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**OIL SPILL COUNTERMEASURES
FOR LOW-ENERGY SHORELINES IN CANADA
RESEARCH RECOMMENDATIONS**

OIL SPILL COUNTERMEASURES FOR LOW-ENERGY SHORELINES IN CANADA

RESEARCH RECOMMENDATIONS

by

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SECTION 1.0 INTRODUCTION

In recent years it has become apparent from experimental work and investigations at spill sites that shorelines in high and medium energy coastal environments are capable of cleaning themselves over relatively short time periods. Large spills in these coastal environments do not present major problems for clean-up operations in most cases. It has become evident that a greater problem exists in low energy environments where stranded oil at the shoreline is not cleaned rapidly and can persist over relatively long time periods to impact the shoreline. The purpose of this study is initially to investigate the state-of-knowledge concerning the impact on the coastal ecosystems and on human useage of low energy shorelines in Southern Canada. This investigation involves an evaluation of existing cleanup technology to determine whether or not adequate restoration procedures exist in low energy shoreline environments to mitigate the potential long-term adverse effects of stranded oil.

1.1 Objectives

A consequence of this review on the state of knowledge regarding impact and restoration aspects of oil spills in low energy environments is the definition of subjects or topics that could benefit either from laboratory or field experimentation to redress the poor knowledge-base. Within the context of the Southern Canadian environment the definition of knowledge gaps or information deficiencies is evaluated in the context of associated spill risks and also the frequency of the primary shoreline types in the study area. The final product of this study is the presentation of a series of potential research options that includes criteria that should form part of the experimental design should these projects be implemented.

1.2 Report Format

The first section of this report considers in detail the definition of low energy shorelines. Many studies in the past have simply differentiated between high versus low energy coasts on the basis of

wave energy levels. This is considered to be an inadequate subdivision as it does not take into account factors such as oil persistence and the long term impact on either the coastal ecosystem or on human useage of the shoreline which are a function of many parameters. In some cases oil may persist for years but have a low ecological or human impact. The definition that is developed therefore relates to the requirements for a section of shoreline to be cleaned to prevent oil that may persist for extended time periods having a continued adverse biological or human effect.

The low-energy coastal environments of Southern Canada are considered in terms of 6 primary shoreline types. These are reviewed on the basis of (a) the physical parameters which describe the shoreline, (b) the ecological character of the environment, (c) the human useage of that environment, (d) the impact of oil and (e) the shoreline countermeasures which would be appropriate on that shoreline type. This review of each shoreline type includes an assessment of the state of knowledge with regard to the impact and effects of spilled on the shoreline as well as the state of the shoreline cleaning technology that would be appropriate for each case.

A brief analysis of the geographic distribution and shoreline lengths of each of the major six shoreline types is undertaken in section 4.0. This provides a background to evaluate the relative frequency of each of the shoreline types.

The character of oil movements through the region provides a background on the likely spill risks in terms of potential sources of oil and the size of spills. This brief spill risk analysis also involves consideration of the impact of oil on the shoreline. In this respect the definition of risk, sensitivity, and vulnerability are crucial to a rigorous understanding of the problem. A summary of the risks is presented that combines results from the previous sections on the shoreline types, likely persistence and the impact of different oil types on the shoreline and the recovery potential for different oil types on different shoreline types.

The final background section reviews the state of knowledge of cleaning technology that is appropriate to the shoreline types of the low energy coasts of Southern Canada. This review includes a brief evaluation of the cleanup effectiveness of the different techniques for the different shoreline types as well as the impact of cleanup methods. From this review it is possible to identify areas where cleanup technology would benefit from investigative efforts.

The final section of the report is contained in two sections which (i) initially combine the knowledge and methodology gaps identified by the individual reviews and evaluations described above and (ii) presents a series of research recommendations which could be used for discussion purposes to develop future laboratory or field research programmes. These recommendations are summarised in the final section of the report (8.5).

2.0 DEFINITION OF TARGET SHORELINES

2.1 Introduction

The term 'low-energy shorelines' is commonly applied to sections of coast where shoreline changes take place at very slow rates. The low mechanical levels of wave-energy at the shoreline redistribute little sediment or result in minimal erosion. This definition is very qualitative and can be interpreted in a variety of different ways. From an ecological viewpoint a low-energy shoreline may be considered in terms of the level of biochemical energy within the ecosystem. Thus, for an oceanographer or geologist a marsh may be a low-energy environment whereas for an ecologist a marsh may be considered a high-energy environment. The objective of this study is to consider those sections of shoreline where oil is likely to persist for an extended period of time and to have a continued adverse impact on the natural system. The broad definition that has been developed is one that identifies sections of coast where oil is likely to persist after one year in sufficiently high concentrations, or with a sufficiently high surface cover, to cause an adverse biological or human effect that might result in a requirement to clean up the stranded oil following the initial impact or to protect the shore zone from oil becoming stranded.

If the stranded oil is not removed or cleaned up initially then the continued presence of that oil in the intertidal zone would impede the natural recovery of the system.

The definition that is used in this study takes into account a wide range of factors. These include the following:

- oil type (oil density)
- shoreline type (including permeability)
- residence time of oil on the shore
- impact of the oil (biological and human)
- cleanup requirement
- natural (mechanical) removal

Each of these factors alone is insufficient to evaluate whether or not the continued presence of oil on the shoreline will adversely affect the natural processes or man's activities. The existing data-base for each of

these factors is incomplete in many cases so that the definition based upon the present state of knowledge must necessarily be qualitative to some degree. The following paragraphs identify the primary features of each of the parameters that have been integrated into this definition.

2.2 Types of Oil

The different types of crude and refined oil have been categorised into three groups based on density (Table 2.1). Oil density and oil stickiness are important parameters that relate to the potential for oil to permeate into the sediments and for the oil to adhere to the surfaces of rock or of sediment particles. A light oil, for example, is unlikely to remain on a rock surface irrespective of the angle or slope of the rock but would probably have a high permeability on coarse sediment beaches or on marshes. The persistence of heavy oiled stranded at the shoreline is primarily a function of the permeability of the substrate and would increase as the size of the pore spaces of the substrate increases. These relationships are discussed in more detail and summarised in Section 2.8.

The primary physical characteristics that are important to the definition for this study are, in the order of importance, density, viscosity, pour-point and stickiness. These are summarised in Table 2.1 which also provides examples of the types of crude and refined oils which relate to each category.

2.3 Shoreline Types

Shoreline types have been sub-divided into six major groups based on substrate type and sediment size (Table 2.2). There exists a wide range of physical shoreline characteristics and the definition into these six groups is based upon the importance of the permeability and porosity of the substrate, which controls the degree and penetration of oil into the sub-surface sediments. Rock outcrops are impermeable and the only variable that is considered in the definition with respect to the rock shoreline types is the angle of the rock surface.

TABLE 2.1
DEFINITION OF OIL PROPERTIES
(Buist, pers. com)

OIL STICKINESS	OIL DENSITY		
	LIGHT	MEDIUM	HEAVY
LIGHT	-dens: 650-850 kg/m ³ -visc: 1-100 mPas -pour point: -10°C -e.g., gasoline, diesel, JP-4, condens. No. 1, No. 2, fresh light crude	N/A	N/A
NON-STICKY	N/A	-dens: 850-950 kg/m ³ -visc: 10 ³ -10 ⁴ mPas -e.g., emulsified diesel or fresh crude emulsions	-dens: 950+ kg/m ³ -visc: 10 ⁴ + mPas -e.g., emulsified Bunkers, weathered crude emulsions
STICKY	N/A	-dens: 850-950 kg/m ³ -visc: 10 ² -10 ³ mPas -e.g., Bunker A (No. 4), weathered crude	-dens: 950+ kg/m ³ -visc: 10 ³ -10 ⁴ mPas -e.g., Bunkers B&C (Nos. 5&6), crude oil residue
NON-FLUID	N/A	-dens: 850-950 kg/m ³ -visc: 10 ⁴ + mPas -pour point: 20°C -e.g., waxy crudes	-dens: 950+ kg/m ³ -visc: 10 ⁴ + mPas -pour point: 20°C -e.g., cold Bunkers B&C (Nos. 5&6), tar

dens = density

visc = viscosity

TABLE 2.2
DEFINITION OF SHORELINE TYPES

	SEDIMENT SIZE (mm)	PERMEABILITY
Rock	(solid)	impermeable
Mud	<0.0625	very low
Sand	0.0625 - 2.00	medium
Sandy Gravel	>0.5	medium
Gravel - Cobble	>2.00	very high
Marsh	mud/sand	low/medium

Note: Gravel is any sediment >2.00 mm

Cobble has a size range 64 - 256 mm

Permeability is defined as the property of a material which allows the passage of fluid. The rate of discharge through the material depends not only upon the size of the pore spaces (porosity) but also on the nature of the fluid and on the hydraulic head or pressure of that fluid. The size of the pore spaces is determined primarily by the size of the sediment particles. Therefore cobble sediments have large pore spaces and have a very high permeability. Gravels have a similarly high permeability but if sand is present within the gravel matrix the porosity is reduced considerably and the permeability is similar to that of a sand beach. Permeability of sand which has a diameter of 1.5 mm is more than double that of sand which has a diameter of 1.0 mm, and the permeability for 1.0 mm sand is more than three times greater than that which has a diameter of 0.5 mm. The permeability of fine-grained sediments, such as mud, is very low, except for the case of extremely light oils that become stranded on muds that are not water saturated.

Details of the biophysical character of each of the six shoreline types is given in greater detail in Section 3.0. The distribution of these in the study area is discussed in Section 4.0.

2.4 Element of Time

A time period of twelve months has been chosen as this represents the most common physical and biological cycle that is present in the Canadian environment. Oil that persists for a period of twelve months or longer affects the coastal system for one complete annual cycle. This time element of one year is used irrespective of any ice that may form and decay in the intertidal zone. The presence or absence of ice is considered to be part of the normal annual cycle of events.

2.5 Impact of Oil

The development of the definition considered initially whether or not the presence of oil after twelve months would have an adverse affect on the natural ecosystem or upon man's activities in the shorezone. It was found from this evaluation that the complexity of such an evaluation precluded the development of a meaningful definition. It was decided therefore to

base the impact on the volume of oil that remained after the twelve month period. Review of existing data from spills and from shoreline experiments led to the choice of the following limits for the amounts of oil remaining in the shorezone after twelve months:

1. Heavy oil - 20% surface cover
2. Medium oil - 1% oil-in-sediment concentration by weight
3. Light oil - 0.1% concentration of oil-in-sediment by weight

These limits relate to realistic conditions for each of the major types of oil. It is considered that if the limit was exceeded after twelve months then the presence of oil would impede the recovery of the natural environment or that oil could have an affect by becoming released from the shore to contaminate adjacent locations.

The impact of a heavy oil would be primarily smothering whereas the impact of a medium or light oil would be due to its presence within the sediments or marsh soil. The impact of stranded oil is considered in more detail below in Section 5.0.

2.6 Cleanup of Stranded Oil

The importance of evaluating whether or not the stranded oil will remain after twelve months, or will have a continued impact on the natural environment, is the critical element in deciding whether or not the shoreline should be cleaned following contamination. If it is expected that the oil will reside for more than twelve months and will have an adverse affect then that oil should be removed as quickly as possible following contamination. If the evaluation indicates that oil will not remain for twelve months and will not have an adverse affect on the ecosystem or man's activities then removal of the oil from the shorezone may not be necessary. The impact of a light oil is likely to be immediate but light oils are unlikely to persist for any length of time unless they permeate into the sediments. The decision to clean up a light oil is one therefore that is concerned with very short term effects in most cases as compared to heavy oils which may remain for periods in excess of several years on the shoreline.

2.7 Natural (mechanical) Removal

The rate of natural cleaning, or the residence time, of the stranded oil has been considered in Section 2.5 in terms of the impact that the presence of that oil will have on the natural environment or man's activities. The rate at which oil is removed is a function of a variety of factors that relate to the character of the oil and the availability of mechanical energy to physically remove the oil from the intertidal zone. Throughout this study it is assumed that the oil is stranded within the zone of wave activity. Any oil that is stranded above the normal limit of wave action will persist for considerable time periods as this will be subject to only infrequent physical activity, for example during storms, and the persistence of that oil is primarily a function of biochemical degradation.

Low-energy environments, in terms of mechanical levels of wave-energy, are usually sheltered locations. This sheltering may take the form of a limited fetch area (fetch: defined as the surface area of water over which the wind can blow to generate waves) or it may be a result of shallow nearshore water depths. In the latter case the energy being transmitted by an incoming wave is dissipated before the waves reach the shoreline. An example of contrasting wave-energy levels can be seen on barrier beaches where the open ocean coast is generally exposed to the full force of waves whereas the lagoon side has a small fetch and generally low wave-energy conditions. On high-energy coasts stranded oil may be removed in a matter of hours or days whereas in sheltered environments there is little mechanical energy to redistribute the oil.

2.8 Oil Types, Oil Persistence and Shoreline Types

In order to assess whether or not the presence of oil on the shoreline after twelve months would have a continued impact upon the shoreline, a qualitative evaluation has been made of the anticipated surface cover or concentrations of stranded oil for the different oil types and different shoreline types (Figure 2.1). The basis upon which this diagram was prepared is summarised in the following notes:

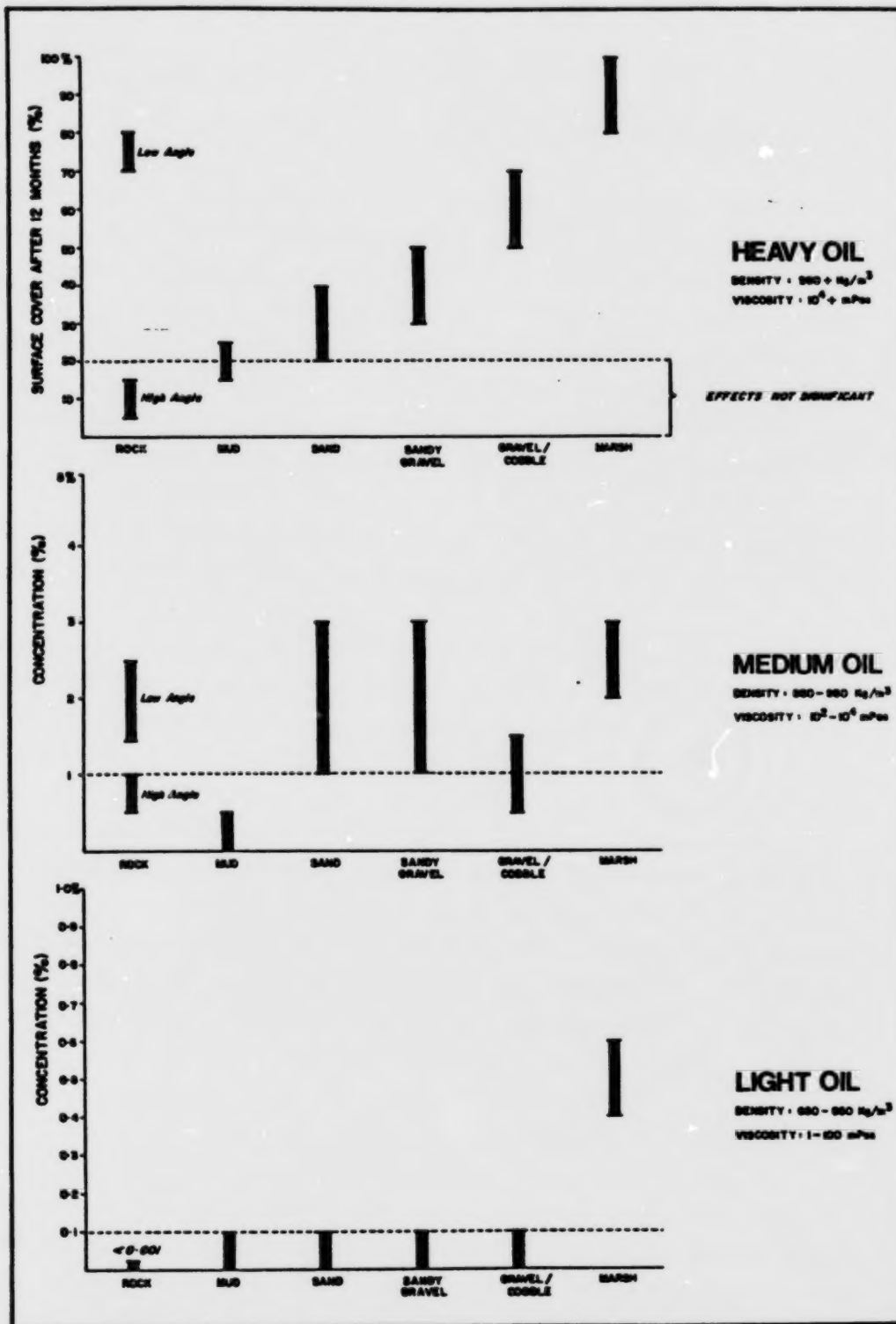


Figure 2.1

Estimated oil retention after 12 months of various oils on different shoreline types.

A. Heavy Oils

Sticky or non-sticky heavy oils are unlikely to remain on rock surfaces except where there is a low angle of slope (30° or less). Muds would be essentially impermeable to heavy oil and it is unlikely that any would remain after twelve months except in the vicinity of the high-water mark. On sand beaches there might be penetration into the surface and near-surface sediments but more oil would likely persist where sandy/gravel sediments were present, as the coarser sediments could become incorporated with the oil to form an asphalt pavement. Penetration could be high on gravel and cobble sediments which have large pore spaces between the particles. On marshes the oil would likely persist in high concentrations as marshes are only found at or above the mean high-water mark so that any oil stranded there would be affected by wave activity only at periods of spring tides or storm surges. Marshes are by definition low-energy wave environments so that there would be little mechanical removal of any oil that become stranded.

B. Medium Oils

Sticky or non-sticky medium oils would likely remain on high-angle slopes in only very small quantities, but could persist in low-energy wave environments on medium or low-angle slopes. This type of oil would most likely be lifted off mud sediments and it is unlikely that any of this type of oil would penetrate into a mud substrate. Medium oil would probably penetrate into the surface of sand or sandy/gravel materials but in coarser gravel/cobble sediments would likely be subject to flushing or pumping as ground-water moves through these highly permeable sediments. As with heavy oils, this oil-type is likely to persist in high concentrations on marshes should it become stranded in this low wave-energy environment.

C Light Oils

On rock surfaces it is unlikely that much oil would remain after twelve months even in low wave-energy environments, although some staining of the rocks may be evident. Even light oils are unlikely to

penetrate much into mud and, although traces may persist after twelve months, it is anticipated that these would be in very low concentrations. Similarly it is anticipated that some penetration might initially take place in sand, gravel or cobble substrates but this oil would likely be subject to groundwater pumping and flushing so that little would remain after twelve months. Concentrations of light oil may be high after twelve months on marshes as these oils would be subject only to evaporation and not mechanical removal by wave action.

On the basis of this qualitative evaluation there are twelve situations where oils from the three broad groups on the six primary shoreline types are likely to persist after twelve months in sufficiently high concentrations of with a sufficiently high surface cover to cause an adverse (biological - human) affect that might result in the requirement to clean up the oil immediately following stranding. It is anticipated in these twelve situations that if the oil is not removed initially then the continued presence of that oil in the intertidal zone would impede the natural recovery of the system.

2.9 Summary

- low-energy shorelines are defined as "sections of coast where oil is likely to persist after one year in sufficiently high concentrations, or with a sufficiently high surface cover, to cause an adverse effect that might result in the requirement to cleanup the stranded oil following the initial impact or to protect the shore-zone from oil becoming stranded".
- the primary oil types are defined on the basis of density as: light, medium, or heavy and these can be characterised on the basis of stickiness as: light, non-sticky, sticky, and non-fluid.
- situations in which (a) oil is likely to remain after 12 months and (b) is likely to involve a significant impact on low-energy shore are:

heavy oils

rock (low angle)
sand
sandy gravel
gravel/cobble
marsh

medium oils

rock (low angle)
sand
sandy gravel
marsh

light oils

marsh

3.0 SHORELINE TYPES

3.1 Introduction

Within Southern Canada there exists a wide range of shoreline types. The substrate and morphological character have been simplified for this study into six major categories. These categories are based primarily upon the nature of the substrate. Mud sediments may occur in such diverse environments as the tidal flats of the Bay of Fundy, sheltered lagoons of the Southern Gulf of St. Lawrence, or the mouth of the Fraser River Delta in British Columbia. Despite the contrasting morphological and environmental conditions in which mud may occur, the properties of the sediments are nevertheless relatively uniform with respect to the impact and persistence of stranded oil. Similarly, bedrock outcrops have a wide range of resistance to weathering processes, with the sandstones of Prince Edward Island being eroded at rates in the order of more than 1.0 m per year whereas the granite outcrops of Newfoundland change at rates that are measured in centuries rather than years. The morphological variability of bedrock outcrops, in the form of platforms, stacks, ramps or cliffs is significant in the context of oilspills only in the context of the slope angle of the rock surface. On vertical surfaces virtually no oil would remain, even after a very short time period, whereas on horizontal rock platforms there exists a greater likelihood that medium or heavy oils may not be refloated by tides and waves and may remain in large quantities for extended periods of time.

This section describes each of the six major categories of shoreline types in terms of the physical and biological character and identifies geographical variations that may exist within the study area. These characteristics are presented in a summary format along with a brief identification of potential spill impacts for each shoreline type.

Rocky shorelines support a substantial biomass but there are very significant variations as one moves from cold to warmer climates. In sub-arctic and cold temperate regions, ice scours the intertidal zone for at least part of the year so that little permanent macroflora and fauna can become established. In hot temperate regions high temperatures and high light intensities can be too severe to allow macro-organisms to survive.

The rocky shoreline is unique in that it alone among the shoreline types considered here, presents a stable, relatively impenetrable substrate to biota. For this reason, rocky shorelines support a unique biota composed of species that are largely sedentary and that have developed methods of attaching themselves to the rock substrate. The shoreline community is composed of:

- attached macro-algae, such as *Porphyra*, *Fucus* and *Chondrus*;
- sessile or attached invertebrates, including sessile bivalves (*Mytilus* spp), barnacles (*Balanus* spp), starfish, whelks and snails;
- and highly mobile forms such as amphipods and isopods that are epiphytic on the fronds of the attached algae.

The stability of substrate gives rise to a unique aspect of rocky shoreline ecology that is important from the point of view of the oil spills. The stability of rocky shore substrate, which differs from the instability of sediment shorelines (sand, gravel, etc.) not only permits colonisation by unique species, but makes possible the protracted interaction of these species giving rise to both dramatic vertical zonation and a pattern of ecological succession that requires years to complete. This pattern of ecological succession involves a protracted sequence of dominant species in which the earliest species to colonise a bare rock surface are replaced by a series of competing species until a relatively stable climax community develops. Members of the climax community have long life histories (many years), unlike many of the species in unstable sediment shorelines which have very short life histories (one or two years). From the point of view of oil spills, this means that when biota are eliminated from a segment of rocky shoreline, although the shoreline may be recolonised immediately by opportunistic species, many years will be required for the serial succession of species in the community that ultimately gives rise to a stable, climax community,

3.2 Rock

3.2.1 Introduction - Physical Parameters

- the character of bedrock outcrops varies considerably depending on whether sedimentary, metamorphic, or igneous rocks are present; unresistant sandstones or shales may erode at rates in the order of 1.0 to 2.0 m per year, whereas the more resistant igneous and metamorphic rocks undergo virtually no change through time.
- the morphological character of bedrock outcrops can range from horizontal through to vertical (Photos 3.1 and 3.2) with surface relief that may range from a rough, pitted or uneven surface with many irregularities to a smooth, flat rock face (Photos 3.3 and 3.4).
- in this study the primary variable for rock shoreline types is related to the angle of the rock surface. Low angle slopes are less than 30° from the horizontal (Photos 3.2, 3.3 and 3.4) and high angle slopes are greater than 30° (Photo 3.1).

3.2.2 Ecological Description and Human Usage

Rocky shorelines are common throughout the study region. In some areas they have amenity value, whereas in others they support fisheries for certain shellfish and attached algae. The basic topography and biological zonation is illustrated in Figure 3.1. The ecosystem extends from the supralittoral zone, which is above the high tide mark and is the transition between the marine and terrestrial environments, to the infralittoral zone which is below the low tide mark and is composed of marine species that do not tolerate exposure to air at low tides. Between these two zones there is an intertidal or littoral zone composed of unique biota which, from an oil spill point of view, is the most vulnerable component of the system since it is most likely to be contaminated with oil during a spill.

The ecology of rocky shorelines is well studied and reviewed. These reviews include works by Carefoot (1977), Lewis (1964), and Stephenson and Stephenson (1972).

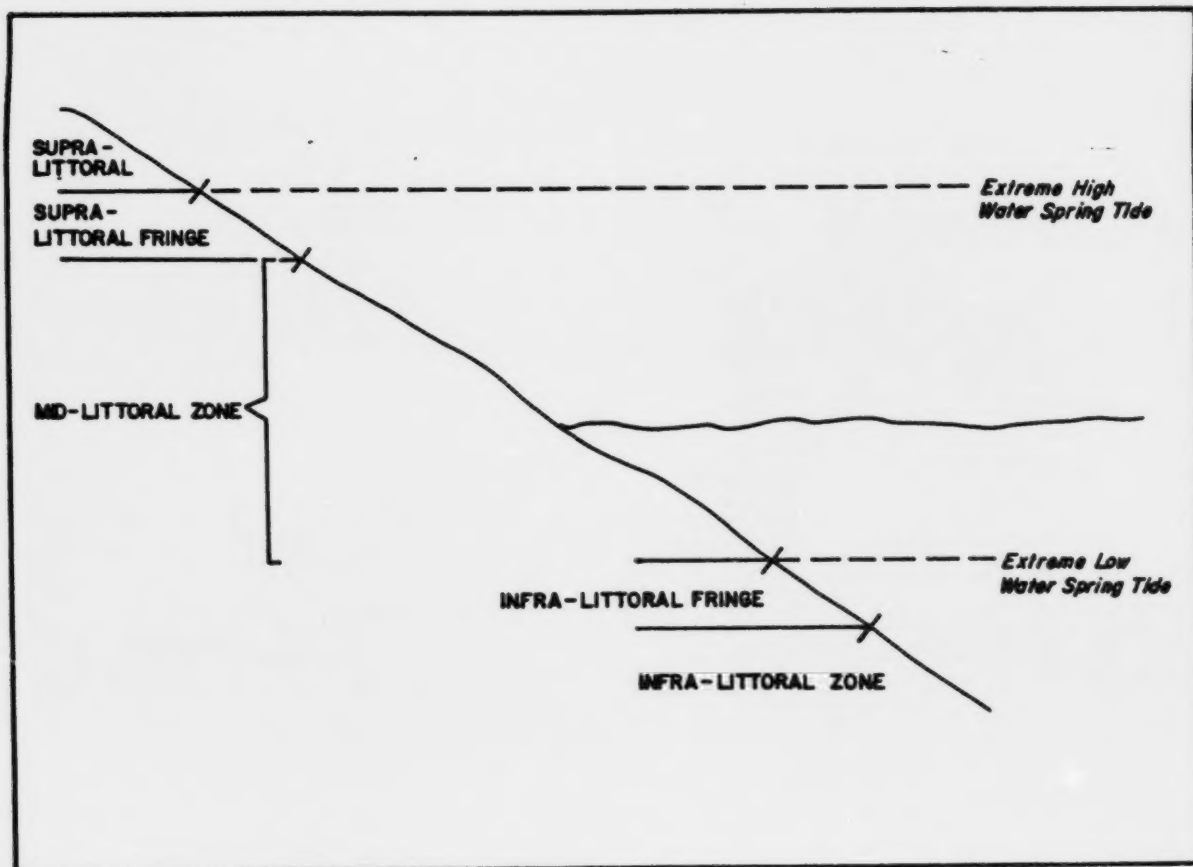


Figure 3.1 Structure and biological zonation of rocky shores

The energetic requirements of the rocky shoreline community are provided by both in-situ production as well as imported material such as phytoplankton and particulate organic detritus that is deposited on the shorelines by the waves. There is little information on the total biomass or production of rocky shorelines, but Carefoot (1977) reports that the standing crop of macroalgae of one temperate rocky shoreline system was roughly 4 kg m^{-2} and yielded an annual production of $12\text{--}80 \text{ kg m}^{-2}$ making it one of the more productive shoreline systems.

In view of their high productivity it is not surprising that rocky shores support bird and fish populations. However, rocky shores are not heavily exploited by man. Some fish species have adapted to the requirements of rocky shorelines and exploit the abundant life there. Some species have adapted to life in tidal pools (e.g. the tidepool sculpin - Oligocottus snyderi). One species, the flathead clingfish (Gobiesox meandrium) has adapted to life under rocks, whereas several species, the blenny eels, utilise their eel or snake-like shape to move between and under rocks. These fish species are not heavily exploited.

In spite of the high productivity and standing crops of rocky shorelines, this type of shoreline is not used heavily by waterfowl. Although some shorebirds, (e.g. gulls) prey on intertidal fauna, waterfowl prefer the more hospitable surroundings of mudflats.

Rocky shorelines are not commonly used as amenities and in spite of their high productivity, they are not extensively exploited. However, in some locations shellfish such as the blue mussel (Mytilus edulis) and certain species of macroalgae are harvested.

3.2.3 Impact of Oil and Spill Countermeasures

3.2.3.1 Oil Fate and Persistence

The persistence and impact of oil depends largely on the viscosity of oil and the degree of slope of the rock shoreline. Non-viscous oils, while they may have some impact on shoreline biota, are not persistent as they do not penetrate the substrate and are quickly lost through

evaporation or are removed by wave action. The persistence of more viscous oil is a function of exposure or wave energy, the angle of slope and the smoothness of the rock surface. In low energy environments, heavy or medium oil may persist on low angle slopes for long periods (a decade or more) and is removed only by weathering and biodegradation.

3.2.3.2 Impact of Oil and Recovery

The impact of oil on rocky shoreline ecosystems and their subsequent recovery is a function of a number of variables including: viscosity of oil; the level of oiling; and the persistence of oil on the shoreline. Heavy oiling has caused extensive mortality among both attached macroalgae and macrofauna (barnacles, limpets, crabs, oysters, etc.). However, with lighter levels of oiling and/or rapid removal of oil (as might occur on a highly exposed shoreline with rapid natural cleaning) attached algae and more resistant attached fauna frequently survive the oiling with only some of the more sensitive epiphytic species (amphipods, snails, etc.) being killed. Recovery can be rapid when only epiphytic fauna (amphipods, snails, etc.) are killed, as these are short-lived, opportunistic species. However, when the attached flora and fauna are affected recovery requires many years (5-10 years). Although attached plant species begin to recolonise the bare rock faces within a year or two after the oil has been removed, the return of the community to a stable, climax condition involves completion of a number of intermediate successional stages.

3.2.3.3 Spill Countermeasures

The cleanup of rocky shorelines is likely to be required only where oil will persist for more than a year or where oil has become stranded above the high tide mark. The level of damage to oiled shorelines can be expected to increase with the duration of the exposure and when damage has been done, the presence of oil delays recovery of the system. Baker et al., (1984) have pointed out that even on low energy shorelines the persistence of oil is brief, but cleanup may be necessary if the shoreline is an amenity.

Because the attached algae and sessile macrofauna of rocky shorelines require a lengthy period to re-establish their communities, a high priority should be placed on minimising the damage to these species. However, if considerable damage has already been done to these species, oil should be removed from the shoreline as efficiently and as completely as possible so that the process of recolonisation can begin as soon as possible. The impact of various cleanup techniques on shoreline communities are discussed below:

A. Removal and Disposal

- (i) Manual removal of oil can increase the short-term effect of oil on the shoreline because these methods cause mechanical damage to biota and remove attached organisms such as algae.
- (ii) Vacuum pumps can increase the short-term effect of oil on the shoreline community because this method causes mechanical damage to biota and removes organisms.

B. Removal of Oil

- (i) Flushing can increase the short-term impact of the oil because of mechanical damage to biota and removal of organisms. The degree of this damage is a function of the temperature, pressure and salinity of the flushing waters. In addition, oil that is driven from the shoreline must be contained and removed from the nearshore waters to prevent further contamination of adjacent areas. However, gently flushing with cold seawater will probably cause far less damage than manual removal.
- (ii) Sand blasting and steam-cleaning greatly increase the short-term impact of the oil spill because they cause severe damage to biota. In addition, oil is driven from the shoreline into the nearshore waters where it must be contained and removed to prevent recontamination of adjacent areas.

C. Chemical Dispersants

There is a growing body of information that suggests that dispersants can be used on rocky shorelines without increasing the effect of the spilled oil, provided the more recently developed, low-toxicity dispersants are used. This suggests that dispersants might be considered for use on oil in intertidal areas or mixed with the seawater to flush away oil that has been stranded above the high tide mark. Dispersants alone, however, do little to enhance the disappearance of stranded oil if not accompanied by tidal flushing or man-made flushing.

D. In-situ Burning

Burning is seldom effective in removing all oil from a rocky shoreline and in addition burning will cause severe damage to intertidal biota greatly increasing the impact of many spills.

3.2.4 Conclusions

Natural cleaning of oiled rocky shorelines is rapid for exposed, high energy locations but even in more sheltered locations tidal flushing is sufficient to remove oil from shorelines and shoreline biota in a relatively short time. Therefore cleanup must be considered only in situations where oil has become stranded above the high tide mark or on amenity situations where quick cleanup is indicated. Heavy or medium oils may persist on low angle slopes where tidal water-level movements are insufficient to lift stranded oil. Some consideration should also be given to protection of wildlife where it occurs although there is not the same urgency in the rocky shore situations as in the marsh or mud flat systems. This is because the shorebirds and mammals that utilise rocky shores are less vulnerable and far less sensitive to oiling than are waterfowl that utilise marshes and mud flats.

The recovery time of rocky shorelines is long (5-10 years) for the biological community of attached flora and fauna once heavily damaged. On the other hand, there is no danger of increasing the persistence of oil by driving it into the substrate as is the case on sedimentary shorelines.

Chemical dispersants can be an effective treatment on rocky systems since these speed up the natural cleaning rate in intertidal areas. Baker et al., (1984) have shown that certain of the less toxic dispersants are effective in speeding the rate of disappearance of oil while having little effect on shoreline biota. Dispersants alone, however, appear to have little effect on the persistence of oil above the high tide level. In this situation flushing (physical dispersion) with sea water (ambient) or a sea water/dispersant mixture promises to be effective while doing the least damage to attached flora and fauna. Manual removal might also be considered although this would almost certainly cause some additional damage to the shoreline community. Steam cleaning and sand blasting would certainly cause far more damage to biota than the oil, and their use should therefore be avoided if little damage has already occurred. However, if extensive damage has already been done by the oil, there is little harm in using these techniques if warranted.

3.3 Mud

3.3.1 Physical Parameters

- muds are defined as silt or clay sediments that have a diameter less than 0.06 mm: these fine-grained sediments commonly accumulate in low wave-energy environments and are only rarely found in areas of high-wave activity.
- muds have a very low angle of repose so that the surface of the sediment is usually flat and rarely exceeds 10° (Photos 3.5, 3.7 and 3.8) (channel creeks cut into mud deposits in the Bay of Fundy may however contain steep angles - greater than 45°)
- muds can be easily transported by low velocity currents (either wave or tidal induced) but may be cohesive and resistant to erosion

- permeability of muds is very low and usually muds are water saturated so the the pore spaces are filled; this prevents the penetration of all but the most light oils into the surface
- extensive mud deposits occur in areas of both high and low tidal ranges (e.g. the Bay of Fundy and Northumberland Strait respectively)
- the morphology of tidal mud deposits such as those in the Minas Basin have a very irregular surface due to tidal-induced currents; mud flats that are found in areas of lower tidal range, for example the Fraser River Delta of British Columbia or the rias of Nova Scotia (Photo 3.5), generally have low flat relief that is interrupted only by the tidal creeks.

3.3.2 Ecological Description and Human Usage

Mud flats are accumulations of fine sediments that usually are easily moved by water currents. Hence mud flats form only in areas where the rate of deposition is great enough to compensate for the removal of sediments by wave or tidal action. Muddy shorelines are usually confined to quiet waters because silt settles out of water only when it is quite still.

The mud flats are the simplest of shoreline types considered here. The intertidal zone is composed of a broad expanse of mud flat (Figure 3.2) backed by rock or salt marsh. Unlike sandy beaches the slope of mud flats is very gradual and as a result the water content of the sediments remains high even at low tide due to the capillary action of the closely packed particles. The small size of particles and high water content of the sediment is important from the point of view of oil spills since these properties prevent even light oils from penetrating into the sediment.

The biota of mudflats is similar to that of other sedimentary shorelines in that it is composed of epifauna that inhabit the mud surface and infauna, (either microfauna or macrofauna) that inhabit the interstices or burrow into the substrate. Unlike sandy shores, mud flats possess some rooted vegetation between the tidemarks in the form of stands of eel grass, Zostera, which occurs near the lower edge of the intertidal zone. Much of

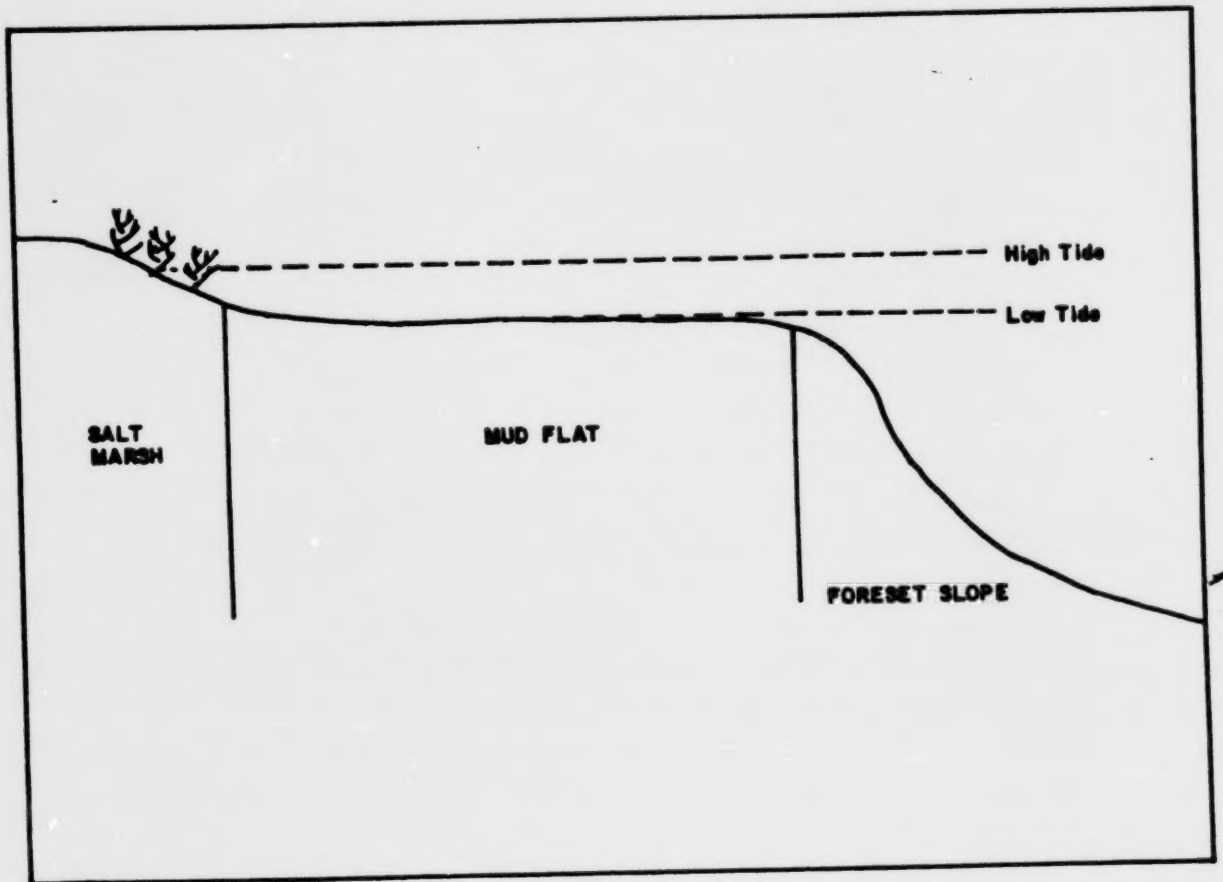


Figure 3.2 Profile of typical mud flat

the energy input is in the form of particular organic detrital material that is carried into the mudflats by rivers; some organic material is provided by phytoplankton; and some is produced in-situ by the microalgae of the flats and by the rooted eel grass vegetation. This abundant energy supports an abundant invertebrate fauna. The infauna makes up the great majority of the fauna. Whereas the fauna of sandy beaches is composed of suspension feeders such as amphipods, the fauna of mud flats is composed primarily of detritivores or deposit feeders such as polychaetes and moleuses. According to Eltringham (1971), the macrofauna is composed largely of lamellicorn molluscs (bivalves) with some gastropods; polychaetes are common; the crustaceans include crabs and mud-burrowing shrimps of genus Callinassa. Representatives of other taxa including Cnidaria and Echinoderms are also found. There are also abundant meiofauna and microfauna.

The abundant secondary production of mud flats is of interest to man. Frequently recreational and commercial fisheries for macrofauna such as crab, clams, etc. are developed to exploit mudflat fauna. On the other hand, the abundant production may be cropped by shorebirds or waterfowl that make extensive use of mud flats in some areas. Johnson and Pastorok (1982) have suggested that the role of secondary consumers in mudflat systems is filled by marine birds such as shorebirds and diving ducks. These replace the demersal fish that perform this function in sand beach ecosystems.

Johnson and Pastorok (1982) have contrasted sandy beaches and mud flats from the point of view of their biology and sensitivity to oil spill impact. The two most important points made by these authors are that, on the one hand, mudflats are far more productive than sand beaches because of the much higher level of imported organic detritus in mud flats. This results in a much higher level biomass on mudflats. From the point of view of oil spills, oil penetrates into sand beaches somewhat more readily than into mud flats because of the smaller pore sizes and higher water content of the latter. In addition, there is an apparent difference in the feeding habits of fauna of sand and mud beaches. The fauna of sand beaches are composed primarily of suspension feeders such as amphipods that feed on suspended sediment particles and phytoplankton, whereas the fauna of mudflats is composed mostly of deposit feeders. Since several authors have

demonstrated that contaminants in sediments are more bioavailable to deposit feeders than to suspension feeders, it should follow that food webs of mudflats are more vulnerable to oil than are those of sand beaches.

3.3.3 Impact of Oil and Spill Countermeasures

3.3.3.1 Oil Fate

In part because of their ability to accumulate oil, mudflats have been considered extremely vulnerable by Gundlach and Hayes (1978). However, only heavy oil would likely persist as light and medium oils would be removed by tidal water movements. Mudflats form only in low energy environments and hence the self cleaning potential of this type of shoreline is minimal. On the other hand, there is little penetration of oil into the sediments of mudflats because of the small pore size and high water content of the sediments. As a consequence, immediately following a spill, stranded oil is floated on the incoming tide and redeposited by the falling tide. This process is repeated until the oil is carried away by currents or until the oil accumulates sufficient sediment and loses its buoyancy. Such heavy oil may be buried by the incoming deposits of silt and organic detritus and persist in the sediments for many years.

3.3.3.2 Impact of Oil and Recovery

The toxic effects of the oil on the biota of mudflats were demonstrated by the presence of dead or moribund macrofauna on flats during the "Amoco Cadiz" spill and the almost complete elimination of infauna during the "Urquiola" incident. Over the longer term, the effect of oiled sediments vary with the degree of contamination. Highly contaminated sediments may prevent recolonization altogether whereas less highly contaminated sediments may cause sub-lethal effects, such as reduced reproductive potential. Contaminated sediments represent a source of chronic contamination for food webs as well as for groups such as clams that are exploited by man. There is considerable evidence that some molluscan species are particularly sensitive to this latter effect because they are deposit feeders and because they are incapable of quickly depurating petroleum hydrocarbons.

As with other sediment types, recovery of mudflat communities to prespill conditions require the depuration of hydrocarbons from sediments and the reinvasion of affected areas by appropriate species. The depuration of petroleum in sediments must be very slow indeed. Since there is little mechanical energy to remove the hydrocarbons, depuration must be through the slow process of chemical and biological degradation. Much of the fauna of tidal flats appears to be longer lived than the opportunistic species that inhabit sandy beaches. As a result, stable populations of these species may require several years to re-establish themselves. On the other hand, the dominant polychaete and mollusc populations of tidal flats develop from highly mobile planktonic larvae and hence re-invasion of the forms is rapid once hydrocarbon contamination levels decline below critical level.

3.3.3.3 Countermeasures

In spite of the fact that mudflats occur in rather sheltered low energy conditions, they possess some capacity for natural cleaning through tidal flushing since oils penetrate very little into the sediments and rising tides simply lift the contaminating oil from the beach surface. There may be some justification for cleanup, however, if important biological resources, shellfish or waterfowl, are threatened, or if oil has been deposited in the upper reaches of a mudflat.

A. Removal and Disposal

- (i) Manual removal probably has little ecological impact if the beach is trafficable and if care is taken to prevent mixing oil into sediments through extensive foot traffic.
- (ii) Vacuum pumps are probably useful in some areas with little ecological impact but care must be taken to prevent mixing oil into sediments through extensive foot traffic.

B. Removal

Flushing may be useful in removing oil and should do little damage to mudflat flora or fauna. Care must be taken to avoid burying large amounts of oil or driving it into the sediments through excessive foot traffic. Care must be taken to collect and remove the flushed oil from the nearshore waters to prevent recontamination of adjacent shorelines.

C. Mixing into Sediments

Mixing into sediments must be avoided because oil in muddy sediments will persist unchanged for many years and serve as a chronic source of contamination (tainting) for exploited macrofauna such as clams, etc.

3.3.4 Conclusions

In some situations, oiled mudflats can be expected to be cleaned naturally through tidal flushing. If this process does not proceed quickly enough, or if wildlife or exploited macrofauna populations are threatened, cleanup might be considered. Heavy oils may persist if these can be floated by tides and water movements. The principle concern in mounting a cleanup operation is that restoration can be accomplished without mixing large amounts of oil into the sediments. The techniques that show most promise in this connection are manual removal and sea-water flushing, both of which appear to promise some chance of success and may be accomplished with the minimum possibility of mixing oil into sediments.

3.4 Sand

3.4.1 Physical Parameters

- the particle size range for sands is 0.06 - 2.0 mm
- in sheltered (low-energy) wave environments the angle of repose of sand deposits is usually less than 20° (Photo 3.9); if the nearshore gradient adjacent to the coast is low, sand deposits frequently have a 'low-tide flat' seaward of the beach face; these flats may be extensive (for example in the Northumberland Strait

area) and frequently have a series of bars or troughs that provide an uneven topographic surface (Photo 3.10)

- sediments on the beachface are tightly packed but have a variable porosity and permeability that depends upon whether medium or fine-grained sands (less than 0.5 mm diameter) are present; intertidal sands on a low-tide flat are usually saturated, which would inhibit the penetration of oil into the subsurface
- sand grains can be removed by low-velocity wave or tidal-generated currents, so that rates of transport (i.e. erosion or deposition) can be high even in sheltered environments
- in terms of the intertidal morphology, sand beaches range from almost horizontal to steep beaches which have a beach-face slope in the order of 20°
- coarse sand (greater than 0.5 mm diameter) has a higher angle of repose and a higher permeability than medium or fine-grained sands

3.4.2 Ecological Description and Human Usage

Sandy beaches are common in all climatic environments. In some areas they represent important recreational resources, whereas in others they are highly productive and are commercially exploited. The basic topography of the beach system is illustrated in Figure 3.3. The functional ecological unit of this sandy shoreline ecosystem extends from the berm to the bar and includes both the sandy substrate and the overlying water envelope, which includes the surf zone. From the point of view of oil spills, the most important segment of this system is the intertidal zone where the greatest degree of hydrocarbon contamination occurs during spills.

The energy source for the macrofaunal and interstitial communities is derived from particulate and dissolved organic matter that is carried to the shoreline by the ocean waves and which filters through the sand matrix and hence productivity is generally much lower than the rocky shorelines or salt marshes which support a high level of intrinsic primary productivity. The ecology of sandy beaches has been reviewed recently by MacLachlan (1985).

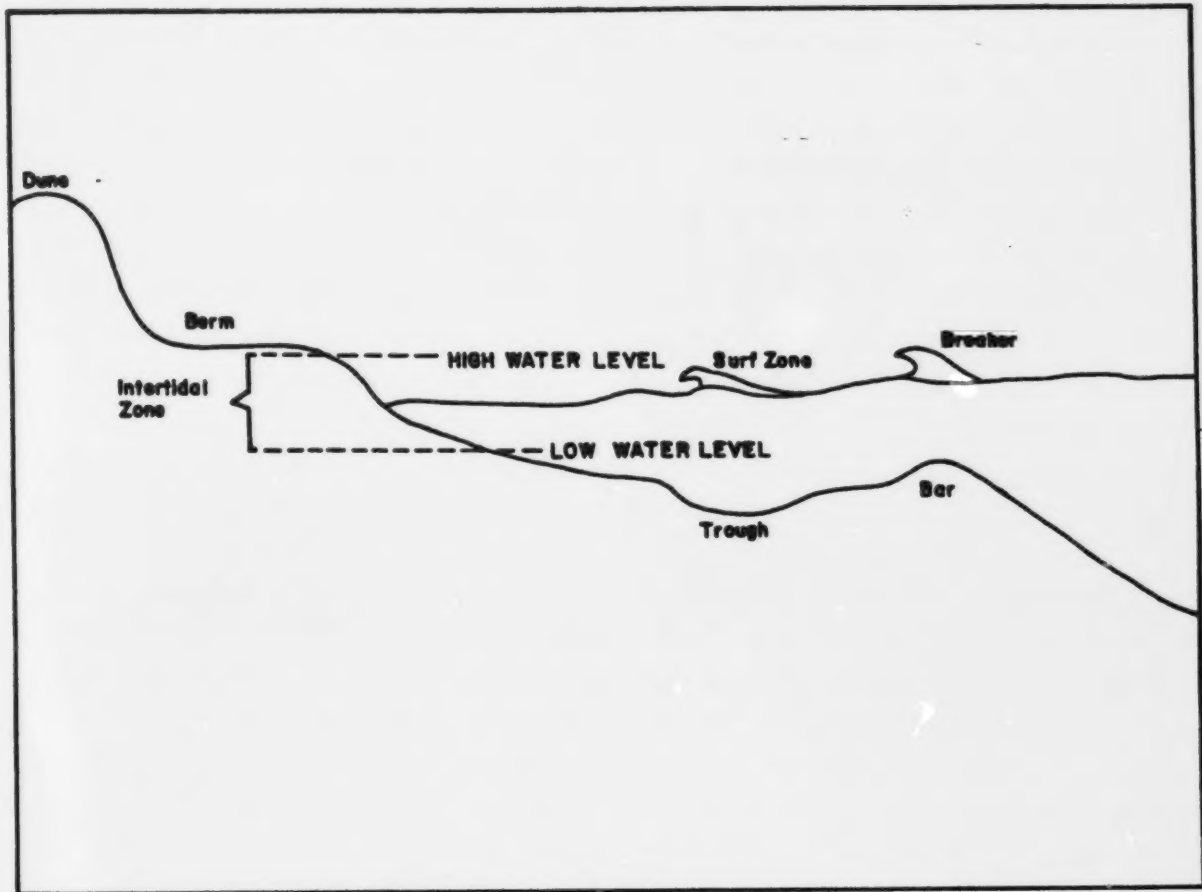


Figure 3.3 Profile of typical sandy beach environment

The sandy beach is characterised by a highly mobile substratum and the absence of attached plants. In general terms, the substratum provides two habitats that support unique communities: (1) the macrofaunal habitat consists of the sand surface and the upper layer of loose sand, and (2) the interstitial habitat which consists of the porous sand body.

The interstitial community is composed of fungi, algae, bacteria, protozoa and very small metazoans. Where sand particles are larger than 200 μm , the fauna are microscopic and inhabit the interstices only, but in fine sands and muddy sands of less than 200 μm diameter, burrowing fauna become more important.

The macrofauna, which inhabit the sand surface are more highly visible but are not as quantitatively important as the interstitial fauna. This community includes representatives of most invertebrate taxa, but it has long been recognised that the following three phyla are the most important:

- (i) molluscs (bivalves and gastropods)
- (ii) crustaceans (amphipods, isopods, mysids, cumaceans, crabs)
- (iii) polychaetes

In overall energy terms, standing crops of biomass on sandy beaches are lower than on rocky shorelines or salt marshes. Bally (1981) surveyed literature on 105 sand beaches and found average biomass values as follows:

- (i) high energy sand beaches, 2 g m^{-2}
- (ii) medium energy sand beaches, 2 g m^{-2} , and
- (iii) low energy sand beaches, 6 g m^{-2}

Comparatively little is known of the fish community of the surf zone off sandy beaches. This community is a highly dynamic assemblage with few truly resident species. The most significant group of fish are the demersal fish as the flatfish (including lemon sole, dover sole, etc.). These feed on the polychaetes of the intertidal zone of sand beaches at high tide. Other groups utilise sand beaches seasonally for breeding. Sand beaches are of great importance in many areas as recreational resources.

Sandy beaches do not support the abundance or diversity of wildlife common of other shoreline types. However, wading birds (gulls, plovers, sand pipers, etc.) are important predators of macrofauna. It is not immediately clear from the literature to what extent the population are dependent on sandy beaches from an energetic or habitat point of view.

3.4.3 Impact of Oil and Spill Countermeasures

3.4.3.1 Oil Fate

The rate of natural removal of oil from a sand beach depends strongly on the degree of exposure and, to some extent, the degree of penetration of oil into beach sediments. On sheltered beaches light oils on the surface of sediments can be removed by tidal action in short time, but medium or heavy oils and oil that becomes buried in sediments can persist for years or decades.

3.4.3.2 Impact of Oil and Recovery

The initial impact of oil on sand beaches depends heavily on the level of oiling, the type of oil and the degree of penetration of oil into sediments (which will in turn be a function of oil type). There is considerable evidence of mortality among macrofauna and infauna during spills. In addition, populations of edible macrofauna can become tainted when inhabiting oiled sediments. The oiled sand beach also poses a threat to shorebirds which are highly sensitive to direct contamination with oil.

The recovery of sand beaches must be considered from two perspectives: (1) the recovery of the biological community, and (2) the restoration of an amenity, so that it can be returned to use as a recreational resource. The latter involves the cleaning of surface sediments only and, as stated above, the speed of natural recovery will depend on the degree of exposure of the beach. The restoration of the biological community following a spill involves the cleansing of both surface and underlying sediments and the subsequent recovery of the damaged biological community to its prespill state.

The natural cleaning of light oils in surface sediments in low energy systems may be rapid through tidal flushing. However, if subsurface sediments in low energy systems become contaminated by light oils these may persist for many years. After contamination of the sediments has declined to background level, some time is required for biological populations to re-establish themselves. The fauna of sand beaches is characterised by opportunistic species with annual life cycles. Annual recruitment into these populations is determined largely by the transport and settling of plankton larvae rather than the reproductive capacity of resident populations. Hence biological populations can recover quickly, within a year or two.

3.4.3.3 Countermeasures

The low productivity of sand beaches and their capacity for rapid recovery offer little incentive to protect the biological community. Hence in selecting cleanup techniques for sandy beaches a high priority should be placed on techniques that are effective while minimising the chances of mixing oil into the sediments where it may persist for years and resurface at a later time. A less priority need be placed on techniques that minimise the damage to beach biota. The results of some cleanup techniques are discussed below.

A. Removal and Disposal

- (i) Manual removal may increase the short-term impact on biota because organisms are mechanically damaged or removed with the oiled. Care must be taken to prevent foot traffic from mixing oil deeper into sediments.
- (ii) Mechanical removal will certainly increase the short term damage to biological system because organisms are damaged or removed, but of greater concern is the likelihood that heavy equipment, especially tracked-vehicles, will mix oil further into sediments if not used following accepted procedures.

- (iii) Sediment cleaning will not increase the level of damage beyond that caused by the oil and removal procedures.
- (iv) Vacuum pumping should cause no more damage than that already caused by the oil, although care must be taken to prevent mixing surface oil into underlying sediments.

B. Removal

Flushing will do little to increase the biological impact of the spill beyond that already caused by the oil. Flushing has two drawbacks however. First the oil must be contained and recovered in nearshore waters so that it does not contaminate the shoreline. Secondly, care must be taken to ensure that flushing does not mix the surface oil deeper into the underlying sediments.

C. Chemical Dispersants

Although chemical dispersants may themselves have some toxic effects on beach fauna that might increase the short-term impact of the spill, their greatest drawback is that they may cause oil to penetrate deeper into the sediments where it may persist for years.

D. In-situ Burning

The principal drawback of burning is that it may render the oil less viscous and cause it to penetrate into the sediments.

E. Mixing Oil Into Sediments

Mixing oil into sediments should be avoided since it simply increases the persistence of oil in the system. From a biological point of view it exposes the community to the threat of chronic exposure to oil. On an amenity beach resurfacing oil becomes a chronic pollution problem.

3.4.4 Conclusions

Many sand beaches display a considerable capacity for rapid cleaning by natural means, but it may be desirable to clean up amenity beaches. First, care must be taken to avoid driving oil from the beach surface where persistence is short, into the underlying sediments where it will be very difficult to clean and where it will persist for years. Second, the biological community is sparse and has a rapid recovery rate and hence damage to biological systems is of less concern in beach environments than in certain other environments.

3.5 Sandy Gravel

3.5.1 Physical and Ecological Parameters

- the shoreline type contains a mixed sediment population comprised of sands (between 0.06 and 2.0 mm diameter) and gravels (defined as any sediment with a diameter greater than 2.0 mm); gravel-sized sediments require considerably higher current velocities for transportation than do sands, therefore gravel frequently remains as a lag deposit as sands are winnowed out
- gravels have a high angle of repose, usually greater than 20° and as much as 40° and often form ridges at the high-water level that are created by the infrequent activity of high-energy storm waves
- sands fill the pore spaces on a gravel beach thus reducing the porosity and permeability to the same level as that of a sand beach
- rates of change on sandy gravel beaches are slow, even if the sand is transported the gravel deposits are usually stable
- gravel occurs most commonly on the beach-face slope and at the high-water mark, with occasional lag deposits in the vicinity of the low-water area
- from an ecological viewpoint the shoreline category is equated with sand beaches (3.4) whereas from a cleanup viewpoint it is regarded as similar to cobble/gravel beaches (3.6)

3.6 Cobble/Gravel

3.6.1 Physical Parameters

- cobbles are defined as a sediment within the size range of 64 to 256 mm diameter; this shoreline type does not include any sand-sized sediments
- the permeability of gravel/cobble beaches is very high due to the large pore spaces between the individual sediment particles
- rates of change are usually low due to the relatively high velocities required for the transportation of gravel and cobble-sized sediments
- due to the high permeability, groundwater table fluctuations are greater than would be the case for sand or sandy-gravel beaches

3.6.2 Ecological Description and Human Usage

The ecology of cobble beaches and their sensitivity to oil spills has to date received far less study than any other shoreline type and as a consequence of the impact of oil is less well understood. This is of concern in the Canadian context since roughly 20% of the Atlantic coastline and 15% of the Pacific coastline is composed of cobble or gravel shores. The limited data base available suggests that biologically speaking cobble/gravel shores form a transition between the highly stable and highly productive rocky shorelines and the far less stable and less productive sandy shorelines.

They differ sharply, however, from these two in terms of their sensitivity to oiling because of the greater permeability of coastal/gravel beaches to oil compared to the other two. The basic intertidal topography of a cobble/gravel beach is similar to that of a sand beach as illustrated in Figure 3.2. From the point of view of spills, the most significant components of the system are the intertidal zone and the area immediately above the intertidal zone where oil may become stranded.

The composition of the biological community of cobble/gravel beaches appears to be highly variable and to be influenced strongly by the degree of exposure to wave action. In sheltered areas where the beach substrate

is rather stable, attached plants may develop providing a high level of primary productivity which in turn provides the energy to support a great secondary production by a faunal community of attached sessile or epiphytic animal life that in many respects is similar to the diverse and productive rocky shoreline community. For the most part, therefore, cobble/gravel beaches, even in somewhat stable areas are relatively devoid of life and are largely insensitive to the effects of oil.

Specific exceptions to this general statement include the capelin spawning areas on the East Coast, which are highly sensitive to stranded oil for short periods each year. The impact on these sections would extend into the marine food web.

Of greatest interest from the point of view of the present work are the sheltered cobble/gravel beaches composed of somewhat stable, poorly sorted sediments consisting of cobble, gravel, as well as sand and perhaps mud. For many of these communities that do not support attached macrophytes, the fauna are supported by imported detritus and then the community is composed of detritivores such as amphipods. According to Simenstad et al., (1979), these detritus-based communities support fewer shorebirds than do rocky shorelines which is consistent with their lower overall productivity. There is little evidence that these cobble/gravel shorelines support fisheries. Indeed, their sole human use appears to be as visual amenities.

3.6.3 Impact of Oil and Spill Countermeasures

3.6.3.1 Oil Fate

The fate and persistence of oil on cobble/gravel beaches depends primarily on oil viscosity, the degree of exposure of the beach and the sediment particle size. Oils of all kinds penetrate quickly because of the large spaces between particles on shingle or cobble beaches. However, light and medium oils are generally non-persistent on these beaches because of the high flow-through rates associated with tidal flushing. Oils that persist on sediments above the high tide mark on exposed cobble beaches and on the surface of sediments are the only candidate for cleanup.

3.6.3.2 Impact of Oil and Recovery

Even the limited database available is sufficient to show the short-term and intermediate-term effects of oil on cobble/gravel shores. The data from a variety of spills have shown that groups, including bivalves and gastropod molluscs and many forms of crustacean macrofauna, have suffered heavy mortality during spills. These reports also demonstrate that oil, although heavily weathered, persisted for several years at some sites and was presumably responsible for the chronic hydrocarbon contamination of otherwise edible resources such as mussels. There is little data concerning any effects on the sparse wildlife.

The complete recovery of heavily affected cobble/gravel shorelines will require several years after the shore is cleaned of the oil. Many of the principal faunal species develop from a planktonic larval stage and hence recruitment will be rapid. Although many species have short life histories (univoltine or bivoltine), some of the macrofauna require several years or more to grow to adulthood and reproduce.

These latter species will require several years to recover to pre-spill conditions. So little is known about this type of ecosystem that it is unclear whether successional dynamics of the kind observed in rocky shorelines, will play in the recovery process in cobble/gravel shorelines.

3.6.3.3 Countermeasures

Cobble/gravel beaches have little amenity value nor do they appear generally to support significant amounts of wildlife or significant fishery resources and it is hence difficult to justify their cleaning. However, when these beaches have amenity value cleaning can perhaps be justified. Since the intertidal zone is likely to be self-cleaning if light oil is stranded, cleanup activities would be restricted to oil stranded above the high tide level and to heavy or medium oil on productive shorelines.

In sheltered cobble/gravel environments oil left on the surface represents a chronic source of contamination for adjacent biota. Spill cleanup might cause some additional damage to the ecosystem but the recovery time of the damaged system promises to be of the order of several years, whereas the oil might remain stranded on the shoreline for a much longer time. There is some justification therefore for cleaning these shorelines, but priority must be placed on selecting a cleanup method that will not promote the mixing of oil into sediments where it may persist for years. The merits of several effective cleanup techniques are discussed briefly below.

A. Removal and Disposal

- (i) Manual removal might cause some increased mortality through the effects of both cleanup procedures and foot traffic, but these effects will be minor. Care must be taken to prevent the mixing of oil into sediments.
- (ii) Mechanised sediment removal obviously results in the loss of biota that will be removed with the contaminated sediments. If removal of surface sediments results in substrate instability that recovery of biota will be retarded until physical processes re-establish substrate stability. Otherwise populations of many species having short life histories will recover very quickly while other larger species may require several years to recover to pre-spill levels.
- (iii) Sediment cleaning will have similar effects to mechanical removal except that delays due to sediment instability will be minimal.

B. Removal

Flushing can contribute to the effects of spilled oil on shorelines if surface organisms are removed or killed through the physiological effects of warm or fresh water. These effects can be avoided through the use of low energy flushing with cold seawater. There are two

additional difficulties with flushing. First, on coarse sediment beaches flushing can contribute to mixing oil deeper into sediments. Second, oil that is flushed off the beach into nearshore waters must be contained and removed to prevent contamination of adjacent areas.

C. Chemical Dispersants

With the advent of modern low-toxicity dispersants there is little likelihood that dispersants themselves will contribute to the impact of the spill. It is unlikely that the use of chemical dispersants alone will be effective in reducing the persistence of oil in low energy environments. Indeed, dispersants might even accelerate the penetration of oil into sediments and thus increase persistence. However, if dispersants are used in conjunction with other procedures such as flushing, they may enhance the effectiveness of the procedure except where highly viscous oils or viscous oil-water emulsions are concerned.

D. Mixing

Mixing of oil into sediments is a simple short-term countermeasure for restoring amenity beaches. In addition to the short term biological effects caused by this mechanical disruption, the oil in the substrate will persist for years disrupting the biological community within the sediments, and possibly resurfacing at a later time.

3.6.4 Conclusions

The data base regarding the ecology of cobble/gravel shorelines and their sensitivity to oil spills and spill countermeasures is by far the poorest of the five shoreline types considered here. Hence many of these conclusions must be considered speculative and tentative. The sparse data appears to suggest that many cobble/gravel shorelines have a capacity for self-cleaning and therefore cleanup should be contemplated only in sheltered locations or in locations where oil has become stranded above the high tide mark. In selecting a cleanup procedure for these situations priority must be given to techniques that will be effective in removing the

oil while minimising the chances of mixing the oil deeper into the sediments. These techniques include manual or mechanical removal and disposal, sediment cleaning and flushing (possibly with dispersants). A lesser priority is placed on the protection of resident flora and fauna because the recovery of a damaged ecosystem promises to be more rapid than the rate of natural disappearance of oil on the surface or buried in sediments.

3.7 Marshes

3.7.1 Physical Parameters

- marshes are vegetated mud or sand flats which have a distinct morphological and ecological character
- marsh surfaces are at or above the mean high-tide level and consequently are flooded by only the high spring tides
- tidal or wave-induced currents which flow over the marsh surface are of a low velocity due in part to the baffle effect of the surface vegetation cover
- rates of change in marshes are usually relatively slow, except at the edge where erosion and deposition may occur as a result of wave or tidal-induced processes
- salt marshes are generally flat in form, broken only by the presence of tidal creeks (Photo 3.15)

3.7.2 Ecological Description and Human Usage

Salt marshes are common in temperate zone areas around the world. They differ from other types of sediment shorelines in that they have a dense cover of rooted vegetation. They develop in sheltered areas where sediments accumulate and where seedlings of rooted plants can become established. They are part of a much larger system, the tidal marsh-estuary ecosystem, which is one of the most biologically productive of all ecosystems, either aquatic or terrestrial.

Although there is considerable variation in the structure of salt marshes from one location to another, many share certain common elements that are shown in Figure 3.4. These include :

- (i) a seaward mud flat or sand flat in the lower inter-tidal zone
- (ii) a low marsh zone of low vegetation commonly composed of Spartina alterniflora also in the intertidal zone
- (iii) a high marsh or inner marsh zone that is inundated only by the high spring tides and by storm surges
- (iv) a land ward transition zone that leads to upland vegetation or to a freshwater swamp

From the oil spill perspective the most important segments of this shoreline are the low and high marshes because they are the areas that are most likely to become oiled while they are highly productive and are heavily utilized by waterfowl for food and nesting sites.

The structure of salt marshes is also significant because under fair weather conditions and average tides, only the intertidal zone becomes oiled during spills but during spring tides or storm surges, oil may be pushed into the upper reaches of the marsh as was the case in the Arrow spill.

As mentioned above, the salt marsh is one of the world's most biologically productive ecosystems. Teal and Teal (1969) suggest that salt marshes can display a biological production of $1000-2000 \text{ g/m}^2$ annually. According to Barnes and Hughes (1982) from $200 - 100 \text{ g m}^{-2} \text{ yr}^{-1}$ of this production is carried into the subtidal areas by tidal flushing where it supports extensive secondary production in the form of finfish and shellfish populations. This production is based mostly on the activity of rooted vascular plants, but there is some production contributed by algae.

This primary production also forms the basis for important secondary production within the marsh. The invertebrate fauna of the marsh play an important trophodynamic role in making energy available to fish and wildlife. In the intertidal zone, the more important faunal forms are the crustaceans (fiddler and marsh crabs); molluscs (mussels,

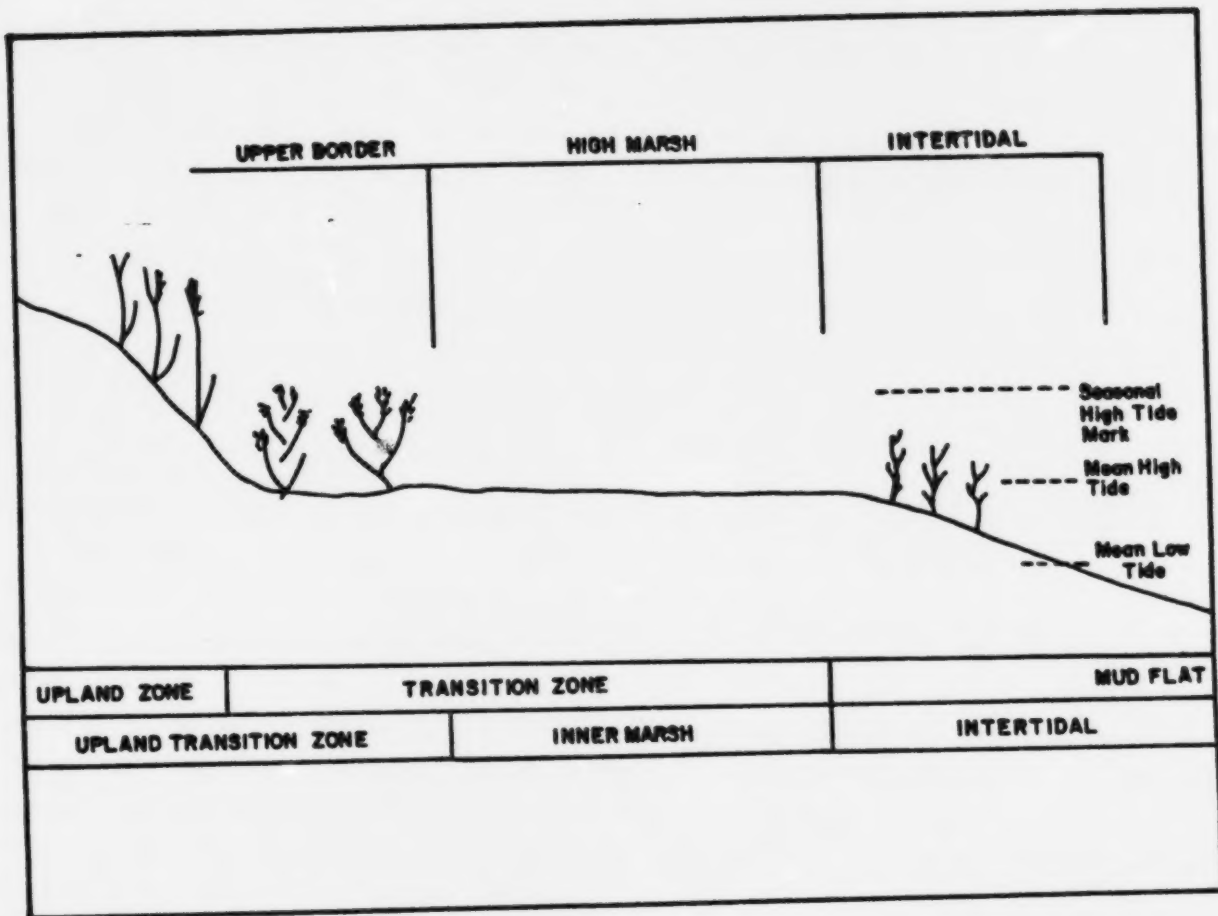


Figure 3.4 Profile of typical salt marsh

periwinkles, snails) and certain insects. In the high marsh the primary consumers on vascular plants are insects (leaf hoppers, flies and bugs), while the algae and detritus are consumed by snails, amphipods and isopods.

The marsh is a primary energy source for highly productive finfish and shellfish populations in adjacent waters (often estuaries), while the marsh creeks themselves often serve as nurseries and spawning grounds for fish and other marine organisms. In addition, these coastal marshes play a highly significant role in waterfowl and shorebird production, serving as breeding grounds, wintering areas and important staging or stopover sites for waterfowl migrations. The primary values of marshes for human use revolve around exploitation of the fish and wildlife resources of the marshes.

3.7.3 Impact of Oil and Spill Countermeasures

3.7.3.1 Oil Fate

The distribution and persistence of oil within salt marshes depends largely upon the sea conditions (sea state, tidal amplitude) during the spill and the viscosity of the oil when it comes ashore. At low sea states, oil is deposited only in the intertidal areas and possibly on the intertidal margins of creeks within the marsh. However, storm surges or high spring tides can distribute oil into the inner marsh, thus contaminating a much larger area and depositing oil in areas where it is likely to be removed by subsequent tides.

Once oil has entered the marsh, the persistence and movement of oil depends heavily on the oil type. Heavy viscous oils coat the vegetation and sediments, but do not penetrate the sediment to any extent. Since there is little wave action to remove oil from the marshes, oil may persist on the surface of months or even years. This oil however, weathers quickly to a tarry residue which is much less toxic than fresh oil.

On the other hand, light, non-viscous oils appear to penetrate the sediments readily. Once in the sediments these hydrocarbons are removed (at least in the intertidal area) by natural flushing, evaporation and biological degradation, but this process is very slow. High concentrations of hydrocarbons can persist for as long as five years and probably much longer. Teal et al., (1978) showed that hydrocarbon concentrations in the parts per thousand range has persisted in marsh sediments eight years after a spill of No. 2 fuel oil at West Falmouth.

3.7.3.2 Impact of Oil and Recovery

The biological effects of oiling on salt marshes appear to be strongly determined by the level of oiling and the viscosity of the oil. In the salt marsh environment, viscous oils appear to pose a significant short term hazard to the biological community but in the long term they are of less concern than non-viscous oils. In the short term viscous oils have some significant effects on salt marsh biota, affecting plants by coating the leaves and stems. There is evidence that some species are resistant to the effects of oil. The common inter-tidal plant species, Spartina alterniflora, exhibit little die-off of existing plant material even when oiled at rates of 2 L M^{-2} , although it does exhibit a reduction in its photosynthetic rate. In addition, several authors have reported new shoots growing through oil covered sediments, indicating that Spartina populations would recover quickly even if damage were to occur. This optimistic note must be viewed with caution however, because Thomas (1977) showed that Spartina oiled with viscous oil during the "Arrow" spill showed few immediate symptoms of pathology and did not display maximum mortality until two years after the spill.

There will no doubt be some direct effects of viscous oils on marsh macroinvertebrates, fish and wildlife. There have been reports of mortality of invertebrate fauna during crude oil spills. However, it is difficult to assess from the sparse literature, the longer term effects of persistent, weathered, viscous oils on marsh fauna.

Perhaps one of the greatest concerns regarding the presence of viscous oils in marshes is the potential for effects on water fowl populations, either directly through the oil of birds or through the destruction of habitat. The threat of damage through direct oiling of birds is significant as long as the oil remains fresh. The risk becomes less as the oil weathers however. The destruction of habitat is of less significance since the effect of oil spills are localised and wildlife populations can simply overfly the damaged areas and utilise adjacent undamaged habitat.

Light, non viscous oils appear to have the potential for more severe, longer-lasting effects because they penetrate into sediments where they can damage the roots of marsh plants and where they can persist for many years in toxic concentrations. Light oils have caused the complete eradication of rooted vegetation in contaminated intertidal areas through the toxic effects on roots of existing plants and preventing young plants from establishing themselves for many years (Hampson and Moul, 1978). The destruction of rooted vegetation in the intertidal zone gives rise to accelerated rates of erosion of the intertidal due to the loss of binding effect of plant roots.

Although there is little data, it is possible to speculate that light, non-viscous oils spilled in marshes pose less of a hazard to water fowl than do heavy viscous oils. It would appear that the potential for transferring light oil from marsh plants to birds would however be minimal since non-viscous oils are less persistent in marshes since they penetrate into sediments and volatilise.

3.7.3.3 Spill Countermeasures

Countermeasures deployed in marsh cleaning will be determined largely by the viscosity of the contaminating oil. If the contaminating oil is light and non-viscous, it will rapidly soak into the sediments permitting little in the way of cleanup. However, viscous oils have a much better prognosis for cleanup.

A high priority must be placed on the immediate cleanup of viscous oil in marshes because of the hazard to waterfowl that use marshes on a seasonal basis. Shorebirds and waterfowl may become oiled when using contaminated marsh lands and some mortality will certainly ensue because of the high sensitivity of avifauna to oiling. In certain cases, significant population consequences may result. On the other hand, marsh plants themselves appear to be resistant to the effects of viscous oils (depending upon the dose, of course) and the recovery from damage is rapid. Hence, if there is clearly little hazard to waterfowl, the necessity for cleanup is less. The acceptability of various cleanup techniques is discussed below.

A. Removal and Disposal

- (i) Manual removal and vacuuming increase the level of impact of the oil on marsh biota through mechanical damage and removal of organisms. Care must be exercised to keep foot-traffic from driving oil into the sediments.
- (ii) Mechanical removal or the use of heavy machinery will increase the level of impact on the marsh and will certainly drive oil into the sediments.
- (iii) Sediment removal is unacceptable since this will cause irreversible damage to the marsh substrata and the root systems of marsh flora.
- (iv) Cropping vegetation is acceptable as long as care is taken to prevent penetration of oil into sediments and to prevent damage to root systems. Vegetations will regrow within one year from the surviving root system.

B. Removal

Flushing is a promising technique since it will cause minimal damage to marsh biota; this method does require containment and recovery of oil in the nearshore waters. The efficacy of the flushing procedure

can apparently be enhanced by mixing small amounts of dispersants with the flushing water. It is unclear what effect dispersants will have on the containment and recovery operations.

C. Chemical Dispersant

The use of chemical dispersants alone is questionable since there is no indication that it will enhance the rate of disappearance of oil. On the other hand, dispersants may have a deleterious effect on the above ground portion of plants depending upon the amount used.

D. In-situ Burning

The information base regarding in-situ burning of viscous oils in salt marshes is sparse and there is evidence that effectiveness of burning in removing oil is highly variable. At first glance, burning would appear to have far more disadvantages than advantages including the following:

- (i) burning may cause more mortality to marsh biota than oiling alone
- (ii) burning may leave harmful residues
- (iii) burning may damage root systems in some ecosystems and thereby delay or prevent recovery

It is important to note, however, that the above arguments notwithstanding, burning has long been successfully used as a management practise in managing wetlands for waterfowl. Burning may be successfully used if conducted in accordance with appropriate wetlands management practise (see Hoffpauer, 1967).

E. Mixing

Mixing of viscous oils into sediments must be avoided since it will certainly increase the persistence of oil and it may increase the overall damage to marsh flora through destruction of root systems.

3.7.4 Conclusions

The spill countermeasure decision for salt marshes will be determined largely by the nature of the oil spilled. There is an urgent need for the spill cleanup of more viscous oils in marshes because of the threat to waterfowl, while there is little that can be done to clean up lighter oils which quickly soak into sediments or evaporate leaving little on the surface to be cleaned.

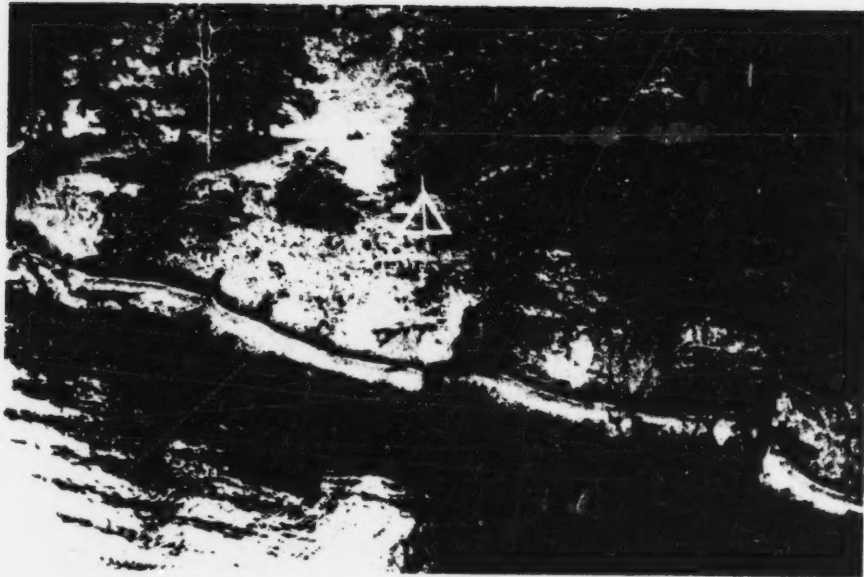
As with other shorelines composed of fine sediments, priority must be placed on cleanup techniques that are effective while minimising the likelihood of mixing oil into the sediments where it will persist for years and may have effects on the root systems of marsh plants. Although it would be preferable to minimise the destruction of the macroinvertebrate fauna and the above-ground portions of marsh plants, regrowth of marsh flora is rapid and some damage to marsh flora could be accepted. These arguments appear to favour the use of saltwater flushing, the effectiveness of which might be enhanced through the inclusion of low levels of dispersants in the water. This technique must be used in conjunction with containment and recovery of oil in the nearshore waters. Manual removal might also be considered as long as care was taken to keep heavy foot traffic from driving oil into the sediments. Mechanical removal techniques should be avoided because of the hazard of mixing oil into the sediments.

3.8 Photographs

The following set of photographs presents examples of the range of low-energy shoreline types that have been categorised for this study. All photographs are from sites within the study area of Southern Canada.

- 3.1 Vertical rock cliff
- 3.2 Ramp rock shoreline
- 3.3 Irregular intertidal rock platform
- 3.4 Smooth intertidal rock platform
- 3.5 Intertidal mud flat
- 3.6 Mud flat with fringing marsh
- 3.7 Mud flat - St. Lawrence Estuary
- 3.8 Mud flat - Lagoon
- 3.9 Sand-beach with wide low-tide flat
- 3.10 Sand-intertidal bars on low-tide flat
- 3.11 Sandy gravel beach
- 3.12 Sandy gravel beach
- 3.13 Gravel-cobble beach
- 3.14 Gravel-cobble beach
- 3.15 Marsh
- 3.16 Marsh

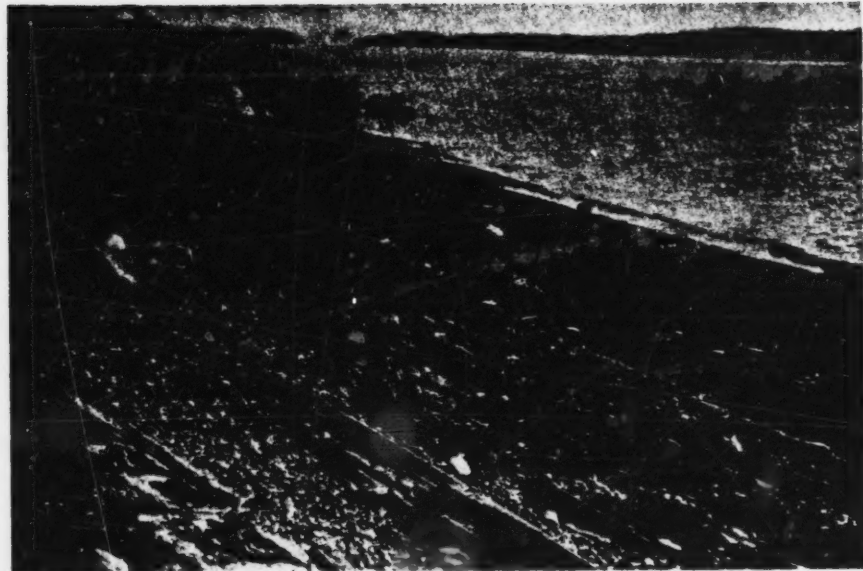
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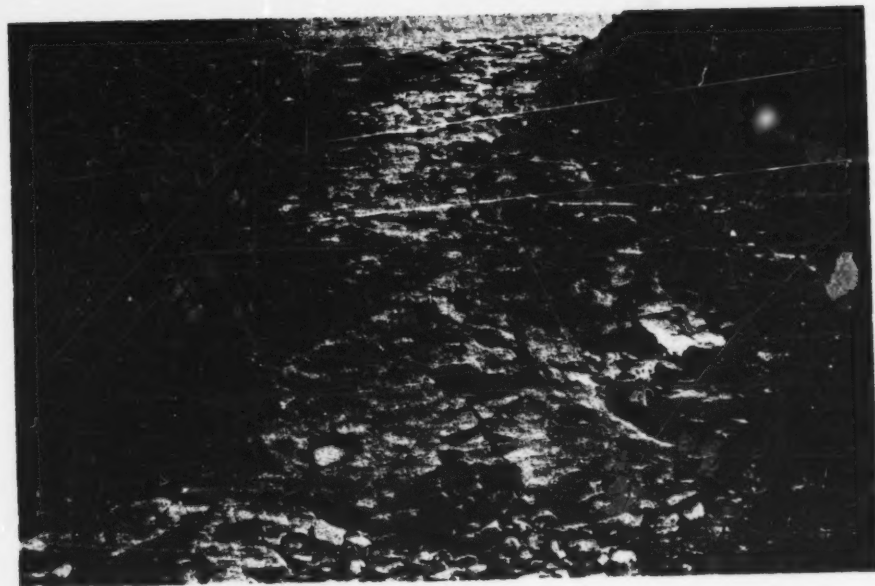
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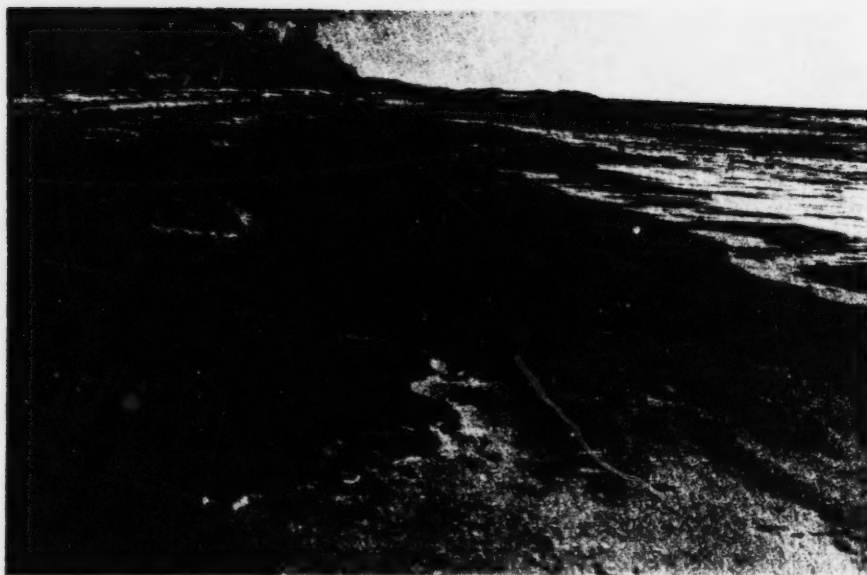
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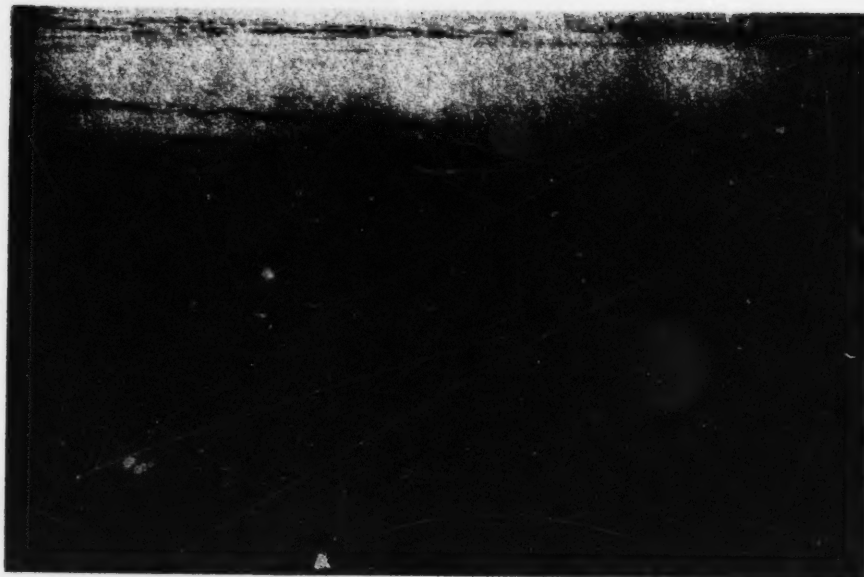
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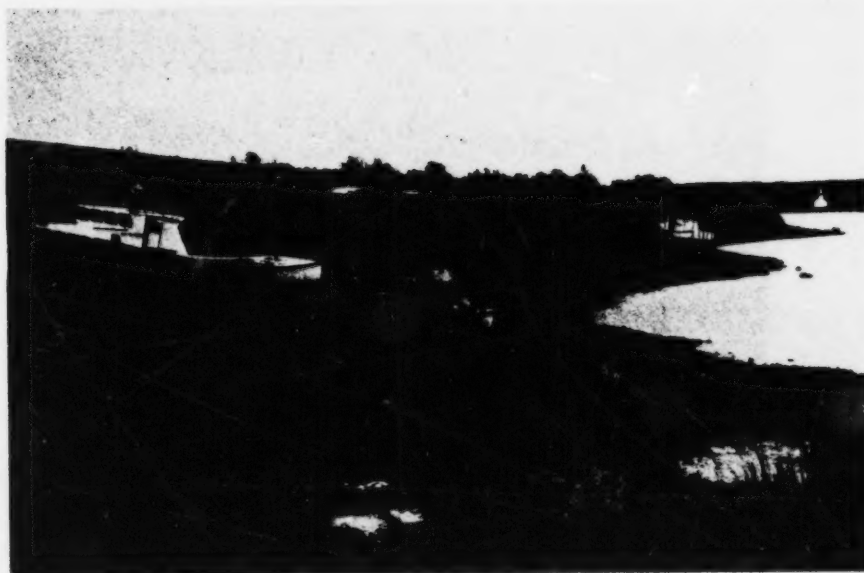


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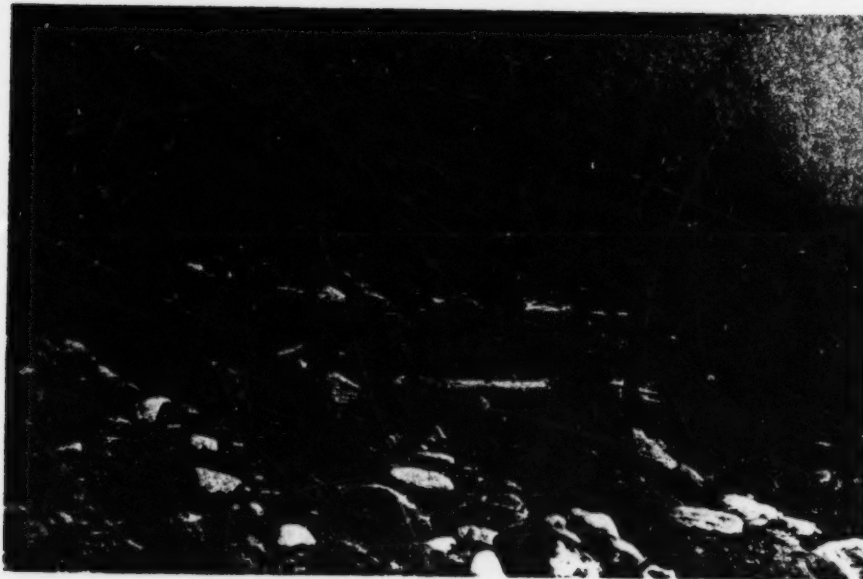


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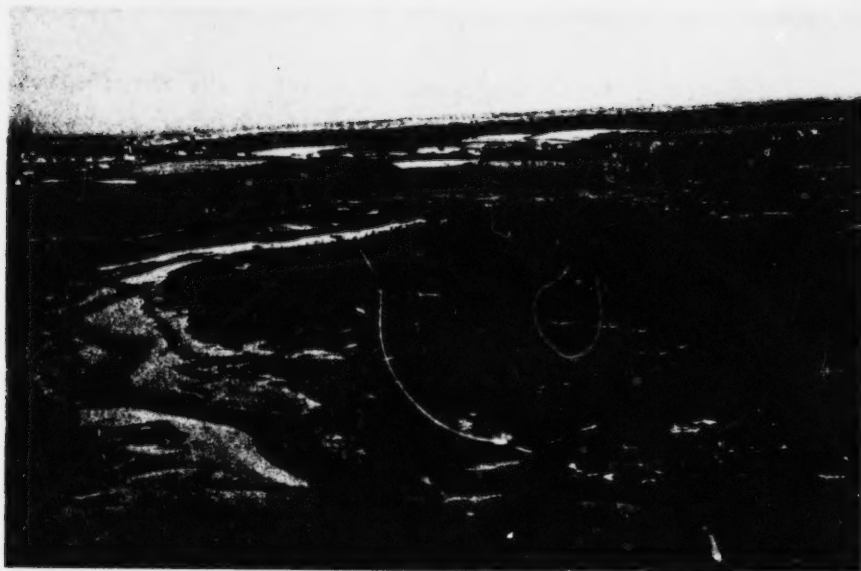
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3.16



3.9 Shoreline Impacts

In this discussion it is important to clarify the terminology that is used. The risk of an oil spill relates to the likelihood of an oil release occurring in the coastal zone or on the adjacent waters. The sensitivity of a shoreline section relates to the tolerance of the ecosystem to spilled oil. A high sensitivity indicating a low tolerance. The degree of sensitivity of similar shoreline environments may vary from one site to another depending on the local ecological character of the shoreline and also upon the type and volume of oil that would reach the shoreline at a given period of the year.

The vulnerability of the shoreline is a combination of the risk and sensitivity factors so that areas of high vulnerability on a shoreline section relate to the high likelihood of oil causing a serious adverse effect upon a shoreline environment. The vulnerability of a mudflat would be low if the stranded oil does not adhere to the sediments, and can be rapidly relifted by rising tides. Similarly, marshes have a low vulnerability during most tidal cycles as oil would be confined to the edge of the marsh, but at times of spring tides the marsh would be very vulnerable as oil could be deposited upon the upper marsh flats.

These definitions are important because areas of high risk that have a low sensitivity are not considered to be critical when compared to areas which may have a lower spill risk but a very high vulnerability and sensitivity. Thus, although the East Coast environment has a high sensitivity in many of the coastal marsh environments, the actual risk on the Atlantic coastline is relatively low due to the lack of navigational hazards and to a relatively low traffic density in that environment. By contrast, the risk in the area of Vancouver Harbour is high, due to the large number of shipping transits, and this is a low-energy environment so that many of the small coastal marshes that characterise the mainland shore are highly vulnerable to small oil spills.

The vulnerability of oil includes assessment of the recovery potential from a spill. Thus the impact must be viewed in terms of both the immediate effects of oil upon contact with a shoreline environment and the longer term effects related to the continued presence of that oil. In low-energy environments that form the focal point of this study it is anticipated that

the oil will remain in the shoreline for a sufficient time period to have an adverse impact on the shorezone. The impacts of various types of oil on the different shoreline types given are summarised in Table 3.1.

3.10 Summary

- Rock
 - heavy or medium oils may be a problem on low-angle slopes.
 - natural recovery may take 5 to 10 years if damage is severe.
 - physical or chemical dispersion techniques and manual removal are effective and well documented restoration techniques.
- Mud
 - oil retention is unlikely except for heavy oils which cannot be lifted by tidal water movements.
 - most cleaning techniques appear to show little promise but manual removal techniques could be further investigated.
- Sand
 - heavy or medium oils may persist, particularly if they permeate the sediments or are buried.
 - biological recovery is likely to be relatively rapid (up to 2 years) as the predominant species are opportunistic.
 - most cleaning techniques are well-documented with the exception of mixing; ecological damage due to cleaning actions is not a major concern in this environment.
- Sandy Gravel
 - heavy or medium oils may persist
 - ecologically similar to sand beaches
 - cleaning technology is the same as applies to gravel/cobble beaches with the exception of mixing which may be applicable but is as yet undocumented.

● Gravel/cobble

- heavy oils are likely to persist.
- ecological damage is likely to be minimal in this type of environment.
- the data base for an evaluation of cleanup techniques is poor.

● Marshes

- all oils will persist if stranded on the marsh surface
- viscous oils will cause less long-term damage than non-viscous or light oils; the latter can cause serious root damage to most plants.
- as the long-term effects of medium or light oils are a concern, there is a strong case for further studies on marsh cleanup technology; in particular, manual and physical dispersion methods are not well documented at present.

TABLE 3.1 Summary of Intermediate and Longer-term Effects of Spills of Various Oils on Different Shoreline Environments.

(NOTE: G = Oil Persistence, V = Damage to Vegetation, A = Damage to Fauna)

ENVIRONMENT	OIL	IMMEDIATE EFFECTS	LONGER-TERM EFFECTS	REMARKS
SAND	Light (gasoline No. 2 fuel, light crude)	G. Oiled V. Up to heavy damage to macroalgae; other damage depends on degree of oiling A. Evidence of heavy mortality among attached macrofauna (mussels, limpets); probably damage also to mobile epiphytic fauna	G. Not persistent V. Heavy damage will require recolonization succession (3-10 years) A. Heavy damage will require recolonization succession (3-10 years); recovery faster if macroalgae not affected (less than 3 years)	
	Medium (mainly crude oils)	G. Oiled V. Up to heavy damage to macroalgae A. Heavy mortality of attached fauna and epiphytic fauna possible	G. Not persistent V. Heavy damage will require recolonization succession (3-10 years) A. Heavy damage will require recolonization succession (3-10 years); recovery faster if macroalgae not affected. (less than 3 years)	Greatest damage is in upper intertidal where oiling is heaviest and where oil is most persistent
	Heavy (Bunker 'C', No. 5 + 6 fuel)	G. Oiled V. Macroalgae killed in some cases, not others A. Heavy mortality of attached fauna and/or epiphytic fauna possible	G. Persistent, sticky (?) V. Heavy damage may require recolonization succession (3-10 years) A. Recovery following heavy damage will require recolonization succession (3-10 years); faster if macroalgae not damaged (less than 3 years)	Is there oil remaining after one year?
MUD AND SAND	Light (light crude and No. 2 fuel)	G. Oiled, penetrates V. ? A. Heavy damage possible, related to level of oiling	G. Penetrates; removal by mechanical and biological processes V. ? A. Recovery of even heavily oiled sites observed to begin within 1 year; completed? - probably less than 3 years	Removal of lighter oils is probably quicker than for medium and heavy oils; recovery of latter two will be delayed while oil remains
	Medium	G. Oiled, some penetration but also mixed in V. ? A. Effects minor in some areas, but some severe effects observed	G. ? V. ? A. Recovery appears to be rapid once oil is removed from sediment, probably 3 years plus (?)	
	Heavy (Bunker 'C' No. 5 + 6 fuels)	G. Oiled, penetration? V. ? A. Reports of mortalities of macrofauna, crabs, clams, worms, etc.	G. ? V. ? A. Reports of recovery time 3 years plus	
GRAVEL	Light (gasoline No. 2 fuel light crude) Medium (medium crude) Heavy (Bunker 'C' No. 5 + 6 fuel)	Information on oil spill impact is sketchy		Persistence of all oils probably minimal; little left after one year; recovery depends on community structure and recolonization patterns and not on oil persistence
SALT MARSH	Light (gasoline No. 2 fuel, light crude)	G. Oiled V. Heavy loss of marsh grass vegetation, including loss of roots A. Interstitial fauna and macrofauna may be killed	G. Penetrates into sediments and persists for 10 years and prevents recovery V. Reestablishment of marsh vegetation by seeds or invasion of roots or underground stems depends on disappearance of hydrocarbons from soil. May take 10 years or longer A. Recovery depends upon persistence of hydrocarbons in soil	Oil appears to be very persistent in marsh soil and recovery is completely inhibited while oil persists
	Medium (mainly crude)	G. Oiled V. Vascular plants vary in sensitivity between species; damage related to level of oiling, heavy mortality possible A. Damage to infauna and macrofauna depends on level of oiling, heavy mortality possible	G. ? V. Recovery quick as long as oil does not penetrate sediments; recovery from light oiling of vegetation is rapid A. Recovery quick as long as oil does not penetrate sediments - 3 years (?)	Oil probably penetrates sediments as recovery is probably long
	Heavy (Bunker 'C' No. 5 + 6 fuel)	G. Oiled V. Damage appears to be related to level of oiling. Heavy mortality of marsh grasses possible A. More evidence of stress than heavy mortality but some mortality must occur to macrofauna. Infauna (?)	G. May be removed from edges but more persistent in beach parts V. Vegetation may be slow especially if oil penetrates into sediments where it will persist for years A. Depends on rate of removal or weathering in oil, probably 3 years plus	Oil probably tends to penetrate sediments to lesser degree and recovery probably quicker as Bunker weather to prevent and become innocuous



Section 4.0 DISTRIBUTION OF SHORELINE TYPES

4.1 Introduction

The study area has been subdivided into five geographic units in order to estimate the geographical distribution of each of the six major shoreline types identified in Section 3.0. The areas are:

1. St. Lawrence River estuary
2. North shore Gulf of St. Lawrence - Newfoundland - Atlantic Nova Scotia
3. South shore Gulf of St. Lawrence
4. Bay of Fundy
5. British Columbia

The relative frequency of shoreline types and the associated length of shoreline for each of the six categories is presented in Table 4.1. These frequency and length values refer to the entire coastline which includes high, medium and low-wave energy environments.

No direct measurements have been made of the lengths of shoreline within each of the five geographical areas using the definition of low-energy shorelines as given in Section 2.0. As this is a multi-parameter definition the value of such measurements is questionable. Rather an evaluation has been made of the estimated lengths of low-energy shorelines (Table 4.2) and of each shoreline type within each geographic area (Table 4.3).

4.2 Frequency of Shoreline Types

The lengths of shoreline types provided in Table 4.1 are derived from previously published literature. These figures represent relatively accurate estimates from which a more qualitative assessment of low-energy shoreline lengths has been developed. The key estimate is that of the estimated proportion of low-energy shoreline lengths, expressed as a percentage of the total shoreline length for each of the five geographic units (Table 4.2b).

TABLE 4.1

(a) Relative Frequency of Shoreline Types

	B.C. (%)	ATLANTIC (%)
Rock	80	25
Mud	2	10
Sand	4	10
Sandy Gravel	7	20
Gravel Cobble	5	20
Marsh	2	5

(b) Lengths of Shoreline Types

	B.C. (km)	ATLANTIC (km)
Rock	20,574	15,880
Mud	514	4,537
Sand	1,029	4,537
Sandy Gravel	1,800	9,074
Gravel Cobble	1,286	9,074
Marsh	514	2,268
Total	25,717	45,370

TABLE 4.2

(a) Estimates of Lengths of Low-energy Shoreline Types by Area (as a percentage of total low-energy shoreline length)

AREA	1	2	3	4	5
Rock	20%	30	20	25	40
Mud	15	10	5	15	10
Sand	5	7	15	5%	7
Sandy Gravel	15	18	25	10%	18
Gravel/Cobble	20	20	25	25%	15
Marsh	25	15	10	20%	10

(b) Estimated Lengths of 'Low-energy' Shorelines

AREA	1	2	3	4	5
Total Shoreline Length (km)	1,545	14,550	3,280	1,413	25,717
Estimated Low-energy Proportion (%)	35	40	20	25	45
Estimated Low-energy Length (km)	540	5,820	656	353	11,573

The estimate was developed on the basis of an evaluation of shoreline complexity within each of the regions. The highest proportion is that for the coast of British Columbia, a highly indented and irregular fjord coastline. By comparison the southshore Gulf of St. Lawrence (Unit 3) has a more regular shoreline with low-energy conditions existing only in the areas of Baie de Chaleur, Northumberland Strait, and in barrier island lagoon systems.

It has been noted the definition of low-energy shorelines is a multi-parameter definition. The basis upon which the estimated low-energy proportion was developed considers results of observations and studies related to experimental and real-spill situations. For example, following the spill of the Arrow in Nova Scotia in 1970 it was estimated that 70% of the contaminated shoreline remained oiled after nine months. This spill in Chedabucto Bay occurred on a range of shoreline environments from exposed Atlantic coast to complex, sheltered environments. The oil that remained in the sheltered areas covered approximately 100% of the shoreline lengths whereas on exposed open coasts virtually no oil remained present. On this basis, for Atlantic Nova Scotia, a value of 40% for the estimated low-energy proportion of the shoreline is considered realistic.

The estimated lengths of low-energy shoreline types have been computed by combining the percentage of low-energy shoreline types (Table 4.2a) with the estimated proportion of low-energy shorelines (Table 4.2b). Thus, although British Columbia has been identified as having an 80% frequency of rock shoreline types throughout the entire region, in terms of the low-energy sections, it is estimated that this frequency is nearer 40% as much as the rock coast of British Columbia is on exposed high-energy sections of shoreline. Similarly almost all of the marsh environments within each of the five units occur within low-energy shoreline types; by definition a marsh is unlikely to be present in any other environment.

The estimates of the lengths of low-energy shoreline types (Table 4.3) indicate that 18,940 km of shoreline, 26% of the total shoreline length of the area, are within the category of low-energy shorelines. Approximately one third of the low-energy shoreline types fall into the rock category and approximately 12% are marshes.

TABLE 4.3

Estimates of Lengths of Low-energy Shoreline Types by Area (in km)

AREA	1	2	3	4	5	TOTAL
Rock	108	1,746	131	88	4,630	6,703
Mud	81	582	33	53	1,157	1,906
Sand	27	407	98	18	810	1,360
Sandy Gravel	81	1,047	164	35	2,083	3,410
Gravel/Cobble	108	1,164	164	88	1,736	3,260
Marsh	135	873	66	70	1,157	2,301
TOTAL						18,940

1. St. Lawrence Estuary
2. Northshore Gulf/Newfoundland/Atlantic Nova Scotia
3. South shore Gulf
4. Bay of Fundy
5. British Columbia

Although these figures must be treated with caution, as they are based on a number of assumptions and a series of qualitative evaluations, they nevertheless provide an indication of the relative frequency of the different shoreline types that are considered in this study.

- 4.3 Summary

- the estimated total length of low-energy shorelines in the study area is in the order of :

11,500 km in British Columbia

5,800 km on the Atlantic Coast

650 km in the Southern Gulf of St. Lawrence

550 km in the St. Lawrence Estuary

350 km in the Bay of Fundy

- in summary the estimated total length of shoreline types on the low-energy coasts of Southern Canada :

35% is rock

35% is either sandy gravel or gravel/cobble

12% is marsh

10% is sand

5.0 SPILL RISKS AND SHORELINE IMPACT

5.1 Introduction

The objective of this section is to identify (a) the risks that exist from potential sources of spilled oil on the water surface or in the coastal zone and (b) the expected effects of the spilled oil in the coastal environments. The first section (5.2) provides a background to identify the most likely spill character, in terms of volume and oil types, as well as the geographical areas where risk is highest. The range of potential oil spill sources includes offshore exploration and production activities, international tanker movements, local trans-shipment of oil products, shore transfer facilities and river pipeline crossings. The most recent estimates (1985) of the input of oil to the global marine environment are given in Table 5.1.

The last section (5.3) identifies the differences that exist between oil spill risks, shoreline sensitivity and shoreline vulnerability. The summary discussion (5.4) presents an evaluation of the likelihood of spills of different magnitudes and different types occurring in the various regions within the study area. This summary includes an evaluation of the expected impact of spilled oil on the low-energy shorelines of southern Canada.

5.2 Sources

5.2.1 Offshore Exploration and Production Operations

The present exploration activities in offshore eastern Canada pose a potential threat of oil spills due to accidents or blow-outs. This risk is not considered to be high, in terms of a potential oil-spill reaching the shoreline, due to a combination of the relatively low-level of activity and to the environmental conditions that would likely carry spilled oil away from coastal environments.

Exploration drilling statistics indicate that a blow-out can be expected on the order of one for every hundred wells drilled, of which on the order of only one in ten would involve the spillage of oil. The worst case situation that could occur on the east coast of Canada during the present period is one where an exploration well were to strike oil in the southern Gulf of St. Lawrence and for a subsequent blow-out situation that would involve the spillage of oil at a site relatively close to the coast.

Studies of spill projectories associated with the oil exploration operations on the Newfoundland Grand Banks indicate the low likelihood of any shoreline contamination occurring as a result of operational accidents in that area. The recent National Academy of Science study (1985) also indicates that offshore production activities account for approximately 0.05 m ta of oil in the global marine environment versus 1.47 m ta for marine transportation (Table 5.1).

5.2.2 Shipping Movements

Canada imports a high proportion of the national requirements. This imported oil arrives by large tankers in either crude or refined form and is subsequently redistributed by onshore pipelines or by small coastal tankers and barges. Over half of the imports are landed and transferred at the east coast ports of St. John, Halifax, Montreal and Quebec City (Table 5.2). This transferring activity involves something on the order of 200 million barrels of oil per year.

In terms of the number of ships in transit, involving all types of cargoes, a pattern of high traffic density for the Pacific Coast and Great Lakes areas becomes evident (Table 5.3). Many communities within these two regions are supplied with petroleum products by small local vessels. The risk of marine accidents is further increased by the character of the water bodies in these areas. Both the West Coast and the Great Lakes are characterised by numerous narrow straits, such as Juan de Fuca, Sault Ste. Marie, the St. Clair River, the Welland Canal and the St. Lawrence Seaway. Thus, the likelihood of a marine accident involving an oil spill is relatively high for these busy and constricted coastal waterways.

TABLE 5.1

INPUT OF PETROLEUM HYDROCARBONS INTO THE MARINE ENVIRONMENT (mta)

SOURCE	PROBABLE RANGE	BEST ESTIMATE*
Natural Sources:		
Marine seeps	0.02 - 2.0	0.2
Sediment erosion	0.005 - 0.5	0.05
(Total natural sources)	(0.025) - (2.5)	(0.25)
Offshore Production	0.04 - 0.06	0.05
Transportation:		
Tanker Operations	0.4 - 1.5	0.7
Dry-docking	0.02 - 0.05	0.03
Marine terminals	0.01 - 0.03	0.02
Bilge and fuel oils	0.2 - 0.6	0.3
Tanker accidents	0.3 - 0.4	0.4
Non-tanker accidents	0.02 - 0.04	0.02
(Total transportation)	(0.95) - (2.62)	(1.47)
Atmosphere	0.05 - 0.5	0.3
Municipal and Industrial		
Wastes and Run-off:		
Municipal wastes	0.4 - 1.5	0.7
Refineries	0.06 - 0.06	0.1
Nonrefining industrial wastes	0.1 - 0.3	0.2
Urban run-off	0.01 - 0.2	0.12
River run-off	0.01 - 0.5	0.04
Ocean dumping	0.005 - 0.02	0.02
(Total wastes and run-off)	(0.585) - (3.12)	(1.18)
TOTAL	1.7 - 8.8	3.2

* The total best estimate, 3.2 mta, is a sum of the individual best estimates. A value of 0.3 was used for the atmospheric inputs to obtain the total, although we well realise that this best estimate is only a centre point between the range limits and cannot be supported rigorously by the data and calculations used for the estimate of this input.

Source: N.A.S., 1985

TABLE 5.2

VOLUMES OF CRUDE OIL OR PETROLEUM PRODUCTS TRANSFERRED (1978)

	MASS (t)	bb1
Saint John, N.B.	9.5 m	76 m
Halifax, N.S.	6.0 m	48 m
Montreal, P.Q.	5.6 m	45 m
Sarnia, Ont.	3.5 m	28 m
Quebec City, P.Q.	3.0 m	24 m
Vancouver, B.C.	1.4 m	11 m
Sept-Îles, P.Q.	0.75 m	6 m
Thunder Bay, Ont.	0.5 m	4 m
Sault Saint Marie, Ont.	0.48 m	3.8 m
Windsor, Ont.	0.45 m	3.6 m
Toronto, Ont.	0.43 m	3.5 m

Source: Statistics Canada, 1979.

TABLE 5.3

PORT RANKING BY NUMBER OF SHIP TRANSITS
(1978)

PORT	NO. OF TRANSITS
Vancouver, B.C.	24,143
New Westminster, B.C.	6,367
Montreal, P.Q.	5,955
Victoria, B.C.	4,789
Windsor, Ontario	3,404
Halifax, N.S.	3,036
Sarnia, Ontario	3,018
Thunder Bay, Ontario	2,816
Nanaimo, B.C.	2,727
North Sydney, N.S.	2,688
St. John's, Nfld.	2,326
Powell River, B.C.	2,325
Campbell River, B.C.	2,300
Sept-Isles, P.Q.	2,090

Source: Statistics Canada, 1979

The three primary factors that are used to evaluate the risk of an oil spill (oil volume: traffic density: navigational hazards) provide an overall picture of one in which the highest volumes of oil or oil products arrive at the East Coast ports where open ocean conditions and few navigational hazards reduce the risk factor considerably. By contrast the risk is considered to be higher in the more constricted waterways of the St. Lawrence and Great Lakes and on the West Coast where oil transfers by smaller size vessels have a high density and frequency.

The National Academy of Science study (N.A.S, (1985)) indicates flat transport-related spills are primarily due to operational spills are primarily due to oprational spills with the secondary causes related to tanker accidents and bilge or fuel oil losses (Table 5.4) The primary cause of tanker accidents is due to either groundings (25%) or collisions (24%) which accounted for 55% of the transportation oil spills between 1969 and 1973 (Table 5.5).

Over the period 1976/80 only four spills were reported in Canada that exceeded 4,000 barrels of oil. Three of these were from tankers and one was from a bulk carrier that spilt its fuel. Over the longer time period of 1970 to 1980, only seven spills exceeded 4,000 barrels and all but one of these (the Lee Wang Zin) resulted in extensive oiling of the shorezone. Of the major accidents that occurred between 1970 and 1980, 6 of the nineteen related to tanker accidents, 4 were spills from onshore facilities, and the remaining 9 were from ship accidents other than tankers (Table 5.6). Geographically, 5 of the nineteen spills occurred in the waters of British Columbia and 7 resulted from marine accidents on the East Coast of Canada. The remainder of these major spills involved 4 accidents at shoreline installations, 2 shipping accidents in the Great Lakes/St. Lawrence River area and 1 spill in the Arctic.

In summary, the overall risk for marine accidents has characterised a potential for large spills associated with imported oils being carried by tankers on the East Coast, and by smaller spills of crude or refined products being redistributed in the coastal areas of the St. Lawrence Seaway, the St. Lawrence River and on the West Coast.

TABLE 5.4

SUMMARY OF TRANSPORTATION LOSSES (mta)

TYPE OF LOSS	RANGE	BEST ESTIMATE
Tanker operations	0.44 - 1.45	0.71
Dry-docking	0.02 - 0.05	0.03
Marine terminals	0.01 - 0.03	0.02
Bilge and fuel oil	0.16 - 0.60	0.28
Tanker accidents	0.35 - 0.43	0.39
Non-tanker accidents	0.02 - 0.04	0.02
TOTAL	1.00 - 2.60	1.45

Source: N.A.S., 1985

TABLE 5.5
(after Card, et al., 1975)

TANKSHIPS (OVER 3,000 DWT) INVOLVEMENTS 1969 - 1973

INVOLVEMENT TYPE	TOTAL NUMBER OF INVOLVEMENTS	PERCENT OF INVOLVEMENTS	NUMBER RESULTING IN OUTFLOW	PERCENT OF OIL OUTFLOW INVOLVEMENTS	AMOUNT OF OIL OUTFLOW (LT)*
Breakdown	355	11	11	2	29,940
Collision	744	24	126	28	185,088
Explosion	104	3	31	7	94,803
Fire	197	6	17	4	2,935
Grounding	790	25	123	27	230,806
Ramming	473	15	46	10	13,645
Structural Failure	515	16	94	21	339,181
Other	5	-	4	1	54,911
TOTALS	3,183	100	452	100	951,309

* Long tons

TABLE 5.6

MAJOR MARINE OIL SPILLS IN CANADA 1970-1980

APPROX. SPILL SIZE(t)	SHIP/SOURCE	LOCATION	TYPE OF SPILL	YEAR
10,000	Arrow*	Chedabucto Bay, N.S.	Bunker C	1970
7,130	Kurdistan*	Cabot Strait, N.S.	Fuel	1979
1,300	tank farm	Deception Bay, Que.	Diesel, Gas	1970
1,100	Nepco 140*	St. Lawrence River	Fuel	1976
1,100	Lee Wang Zin	Dixon Entrance, U.S.	Fuel Oil	1979
840	Canso Light*	Canso Strait, N.S.	Fuel	1979
500	William Carson	Square Island, Nfld.	Diesel	1976
400	Vanlene	Barkley Sound, B.C.	Bunker B, Diesel	1972
387	Richmond Red*	Dees Island, B.C.	Fuel	1977
331	marine terminal	Gaspe, Que.	Fuel	1979
305	marine terminal	Chicoutimi, Que.	Fuel	1980
300	Carita	Cape Breton, N.S.	Bunker	1975
250	Ostrov Russkiy	Grand Banks	Fuel	1978
240	Freighter	Burrard Inlet, B.C.	Bunker	1973
234	John A. MacDonald	Beaufort Sea	Fuel	1978
230	Imperial St.Clair*	Parry Sound, Ont.	Fuel	1976
200	Irish Stardust	Alert Bay, B.C.	Fuel Oil	1973
204	marine terminal	Marystown, Nfld.	Fuel	1977
200	Sandino	Tracy, Que.	Fuel Oil	1978

* Indicates a tanker spill
Source: NATES - unpublished

5.2.3 Shore Transfer Operations

It is evident from Table 5.4 that 4 of the accidents that occurred between 1970 and 1980 in excess of 1,500 barrels occurred at marine transfer facilities or shoreline storage sites. These sites constitute a particular risk as the contact time for oil to reach the shoreline is negligible and contamination levels are usually very high due to the localised nature of the spill. No survey has been conducted, as part of this study, to identify the total number of shore transfer facilities or the distribution of marine or estuarine pipelines in the regions. It is assumed that the density of these transfer facilities, and also of pipelines, is associated with the density of coastal populations. Similarly, the size of such an installation would be related to the population density of the coastal community.

5.3 Discussion and Summary

For the purposes of this study a brief analysis of spill risks and shoreline sensitivity provides the background to define existing countermeasure knowledge gaps and research needs. Many small spills less than 100 bbl are a common occurrence. These operational spills occur in all areas from many types of activities. This analysis suggests that the low-energy environments of the West Coast and the Great Lakes are the highest risk areas for small spills. Large spills (>100,000 bbl) are likely only on the Atlantic Coast as this is the only area with large-volume tanker traffic.

- the primary risk is related to medium size oil spills (less than 5,000 bbl) of refined products in coastal waters from collision or the grounding of small tankers or other vessels engaged in local activities; such a spill could result in contamination of large sections of low-energy shoreline and/or heavy local contamination that could likely persist for extended time periods.
- such accidental spills would likely occur in or adjacent to low-energy coastal environments and be due to grounding or collision of tankers or non-tanker vessels.

- the risk of a fully laden large tanker causing a large spill (>100,000 bbl) is considered to be very small
- the most sensitive situations are as follows (not in any ranking or degree of severity):
 - rocky coasts - heavy oils/medium oils
 - mud - heavy oils
 - sand - medium oils
 - gravel/cobble - heavy oils/medium oils
 - marshes - all light oils; and also medium or heavy oils if volume high
- the marsh and mud environments are the most vulnerable as these are usually associated with low-energy environments and have diverse and productive ecosystems
- the most likely scenarios for Canadian low-energy environments are:
 - (1) small spills (up to 5,000 bbl) of refined products due to a shipping accident
 - (2) small spills (<5000 bbl) at shore-based facilities
 - (3) operational spills (<100 bbl)

6.0 EXISTING RESPONSE TECHNIQUES

6.1 Introduction

Over the past fifteen years there has been a considerable amount of effort on the development and evaluation of shoreline countermeasure techniques. However, today there are still major deficiencies that exist in our ability to remove oil effectively and practically from the shoreline without causing significant environmental damage. This section reviews the shoreline countermeasure techniques that could be used in terms of their practicality and effectiveness and in terms of the state-of-knowledge for the primary categories of cleanup methods. The purpose of this evaluation is to identify techniques that might have a practical application but that are poorly documented or understood in terms of their potential impact on the shoreline system.

6.2 Shoreline Cleanup Methods

Although there exists a very wide range of mechanical and manual methods for the removal of oil stranded at the shoreline, these can be grouped into four primary categories (Table 6.1). In this evaluation the only modification to Table 6.1 is to separate the removal methods into manual or mechanical techniques.

6.2.1 Manual Removal

The manual removal of stranded oil is considered to be practical and effective for most shoreline types (Table 6.2). This approach will be of less value on mud environments due to potential problems of the movement of personnel in this shoreline type, and on gravel/cobble beaches if the stranded oil has penetrated deeply through the pore spaces into the subsurface sediments. Although practical and effective in most cases it is nevertheless often time consuming and requires substantial manpower resources for the removal of large volumes of oil.

TABLE 6.1
SHORELINE CLEANUP METHODS

METHOD	EXAMPLES OF TECHNIQUES	IMPLEMENTATION
1. Removal/Disposal	earth-moving machinery vacuum pumps shovels, rakes, etc.	motorised manual or motorised manual
2. Dispersion	chemical flushing (low or high pressure steam cleaning sand blasting	manual or motorised manual
3. Sediment Cleaning	chemical washing sieving burning/incinerators	motorised motorised motorised
4. Mixing	mix into sediments push into surf break-up pavement	motorised motorised

TABLE 6.2

CLEANUP PRACTICALITY - EFFECTIVENESS

	MANUAL REMOVAL	MECHANICAL REMOVAL	ONSHORE DISPERSION	SEDIMENT CLEANING	MIXING
Rock	■	○	■	○	○
Mud	▲	▲	○	○	▲
Sand	■	■	▲	■	▲
Sandy Gravel	■	■	▲	▲	▲
Gravel-Cobble	▲	▲	▲	▲	○
Marsh	■	▲	▲	○	▲

■ Practical and effective
 ▲ Possibly useful
 ○ Impractical

TABLE 6.3

IMPACT OF CLEANUP METHODS

	MANUAL REMOVAL	MECHANICAL REMOVAL	ONSHORE DISPERSION	SEDIMENT CLEANING	MIXING
Rock	□	—	▲	—	—
Mud	▲	▲	—	—	●
Sand	□	□	□	□	▲
Sandy Gravel	□	□	□	□	▲
Gravel-Cobble	□	□	□	□	—
Marsh	●	●	▲	●	●

- Severe
 ▲ Moderate
 □ None/low
 — Not applicable

TABLE 6.4

STATE OF KNOWLEDGE OF CLEANUP METHODS

	MANUAL REMOVAL	MECHANICAL REMOVAL	ONSHORE DISPERSION	SEDIMENT CLEANING	MIXING
Rock	○	—	○	—	—
Mud	▲	■	■	—	■
Sand	○	○	■	▲	■
Sandy Gravel	○	▲	■	▲	■
Gravel-Cobble	○	▲	■	▲	■
Marsh	▲	○	■	—	■

○ Good
 ▲ Fair
 ■ Poor

Manual removal of stranded oil is unlikely to have a significant impact on the coastal system except in mud or marsh environments (Table 6.3). In mud the movement of personnel may result in mixing clean subsurface sediments with contaminated surface material if correct procedures are not followed. Similarly, in a marsh environment the traffic of the cleanup participants can cause more damage that was originally caused by the oil alone.

Although there may be minor refinements that could be developed for the implementation of manual recovery, such as the development of specialised rakes or shovels, or the design of special stands to hold bags into which material can be collected, these improvements will probably add relatively little to our present state-of-knowledge. There does exist room for improvement in our understanding of the impact of cleanup methods on mud environments and in the development of more practical and non-damaging manual removal methods for marsh environments. Both of these are not considered to be major knowledge gaps but rather are identified as areas where some improvement could be made (Table 6.4).

6.2.2 Mechanical Removal

The use of motorised equipment to remove oil from the surface was the subject of considerable effort during the 1970's. Motorised earth-moving equipment has been shown to be very practical and effective for sand shorelines and, in some cases, on sandy gravel shoreline types. The equipment is less effective on mud and gravel/cobble shorelines due to the trafficability of equipment across the surface. Motorised vacuum systems can be used in mud, sand, or sandy gravel environments and may be of some value on the outer edges of marshes. Vacuum pumps may frequently used in association with sumps.

The impact of cleanup methods, if applied in accordance with recommended procedures, is unlikely to have any detrimental effect on sand, sandy gravel or gravel/cobble shoreline types. Motorised equipment on a mud substrate may well result in the mixing of clean

and contaminated sediments, and the use of heavy equipment in marshes may similarly have a damaging effect either by mixing oil into the substrate or in the direct destruction of the vegetated surface.

The state-of-knowledge for mechanical removal of sediments on sand and marsh environments is well documented and understood. There does exist room for improvement in our knowledge of the applicability and effectiveness of the techniques for sandy gravel and gravel/cobble shoreline types. The area of potential improvement is greatest for mud environments in terms of both the practicality and the effectiveness of mechanical removal and also in terms of our knowledge concerning the potential impact of such activities on the ecosystem.

6.2.3 Onshore Dispersion

The use of chemical agents or the application of flushing and other mechanical dispersion techniques has been shown to be practical and effective on rock shoreline types if recommended procedures are followed. Dispersion is unlikely to be effective on mud environments and has a limited application for sand and other sedimentary shoreline types. The use of low-pressure water flushing on marshes is recommended for certain situations but other types of dispersion techniques are likely to be damaging and are not recommended in this shoreline environment.

The impact of dispersion techniques is dependent upon the exact technique that is applied. For example, chemical dispersion will have a different impact than would low-pressure water flushing. Sand-blasting, steam-cleaning, and hot water high-pressure dispersion techniques will cause damage on rock environments. However, this damage may be less than that associated with the impact of the oil alone. Dispersion techniques are unlikely to have a significant impact on sand, sandy gravel or gravel/cobble shorelines. Low-pressure flushing is acceptable and will have a low impact for most light and medium oils in a marsh environment if applied correctly. Other techniques however will likely have a damaging effect on vegetative shorelines.

The state-of-knowledge for dispersion on rock substrates is relatively well understood. The methodology and the impact on all other shoreline types is considered to be in a poor state-of-knowledge. Relatively few controlled experiments have been conducted in the field to evaluate the effectiveness and the impact of the range of shoreline dispersion cleanup methods. This area is considered to be one where further work would be able to improve the existing knowledge base significantly.

6.2.4 Sediment Cleaning

The range of chemical, mechanical, or incineration techniques are applicable only to the sedimentary shoreline types. Available techniques have been shown to be practical and effective in some respects for sand-shoreline types, although rates of cleaning are frequently slow in terms of the volume of material that can be cleaned per day.

The impact of the methods is likely to be low due to the low ecological sensitivity of the sedimentary shorelines. If, however, sediment cleaning were to be used in a marsh environment, the impact on that situation would probably be severe. In most cases the use of these techniques for marsh environments is not considered to be practical.

The state-of-knowledge for sediment cleaning is relatively well understood. There is scope for improvement and probably for the development of new techniques. However, as a major tool for the cleanup of extensive lengths of shoreline and high volumes of stranded oil, this evaluation indicates that a knowledge base is fair with respect to the basic concepts of sediment cleaning and in terms of the environmental impact of these techniques.

6.2.5 Mixing

Mixing techniques may be applied to sedimentary environments. The usefulness of such techniques on a gravel/cobble beach is however

questionable due to the slow rate of natural replacement of any clean material that may be pushed into the surfzone. In addition, the poor trafficability of motorised equipment upon gravel/cobble beaches is likely to make such potential techniques impractical.

The potential impact of mixing is likely to be high on both mud and marsh environments if such techniques are considered to be practical on these shoreline types. The impact of mixing on sand or sandy gravel beaches is likely to be moderate if this action results in burial of contaminated sediments below the beach surface.

The state-of-knowledge for the application and impact assessment of mixing techniques is poor. No documented studies have been identified so that the evaluation presented in this section is necessarily speculative. There exists considerable potential to increase the knowledge base on the value and on the impact of mixing techniques as so little is known about them at present.

6.2.6 Natural Cleaning

Stranded oil is removed naturally by coastal processes if left untouched by man. This option to allow normal self-cleaning to take place is one of the available options that is considered during the development of cleanup decisions. Whether or not oil would be cleaned by man or by natural processes depends upon an evaluation of the persistence, fate and effects for that particular spill and for that particular location. These factors are considered elsewhere in this report (Sections 2.0 - 3.0). Natural cleaning is included in this discussion as a necessary reminder that it is a practical and effective cleanup option if the persistence of oil in the shorezone is considered not to have an adverse effect.

6.3 Summary

- the situations where cleanup activities
 - (i) have an insufficient knowledge base,
 - (ii) may be practical, and
 - (iii) would be unlikely to incur severe ecological damage are:

mud	-	manual removal
sand	-	mixing
sandy gravel	-	mixing
marsh	-	manual removal
marsh	-	dispersion

- research activities for each of these 5 cases could profitably improve our existing knowledge base for low-energy environments.
- these 5 cases were selected on the basis of the probable likelihood of research efforts providing an improved knowledge base; thus, for example, although the state-of-knowledge for mixing in marshes is poor, this knowledge for this coastal environment was not considered to be worthy of further investigation.

SECTION 7.0 KNOWLEDGE AND TECHNOLOGY GAPS

The purpose of this section is to bring together the varied evaluations that have been presented in the previous sections in order to identify areas or subjects that could derive benefit from future research efforts. Table 7.1 provides a simplified summary of the existing knowledge base concerning the effects of oil spills and existing countermeasure technology for each of the primary shoreline types. This table also briefly identifies the potential that exists for improving the knowledge base where this is appropriate. Thus, for example, although the state of knowledge concerning countermeasures on mud shores is considered to be poor, there is little practical research than can be identified which would significantly improve the poor technology base on this shoreline type.

Taking this overall assessment to a greater level of detail, and including factors relating to the potential ecological impact of oil on the shoreline and the potential oil persistence in combination with the existing knowledge base (Table 7.2), it can be seen that there are a number of areas where further research may be advisable even though the existing knowledge base is good. Such cases exist where the potential ecological impact is high and the expected oil persistence also is high. In Table 7.2 the ratings with respect to the knowledge base for effects and for countermeasure technology that are identified by an asterisk are those where further research could add data that would significantly improve the existing knowledge or technology bases. From these two tables it is apparent that the environments which are characterised by a combination of (i) potential high ecological impact, (ii) potential oil persistence, and (iii) a poor or moderate knowledge base on effects or on countermeasures are:-

- mud - heavy oils
- marsh - heavy oils
- marsh - medium oils
- marsh - light oils.

TABLE 7.1

Overall Assessment of Knowledge Base and Potential for Improvement

SUBSTRATE	KNOWLEDGE BASE		POTENTIAL FOR IMPROVED KNOWLEDGE BASE	
	EFFECTS (INCL. RECOVERY)	COUNTER- MEASURES	EFFECTS (INC. RECOVERY)	COUNTER- MEASURES
Rock	Very Good	Very Good	n/a	n/a
Mud	Good	Poor	Good ¹	Poor
Sand	Good	Very Good	n/a	n/a
Sandy Gravel	Poor	Moderate	Good	Poor
Gravel/ Cobble	Poor	Good	Good	Poor
Marsh	L. ² Good	Poor	Good ¹	Good
	M. Good	Poor	Good ¹	Good
	H. Moderate	Poor	Good ¹	Good

¹ A number of spill sites have been thoroughly studied immediately following the spill and for a few years post-spill, but few sites have been followed long enough to get a good estimate of recovery time. These sites could be revisited ten or more years post-spill.

² L = Light Oil, M = Medium Oil, H = Heavy Oil.

TABLE 7.2
Summary of Potential Oil Impact and Persistence Combined with
Existing Knowledge Base

	POTENTIAL ECOLOGICAL IMPACT	POTENTIAL OIL PERSISTENCE	KNOWLEDGE BASE	
			Effects	Countermeasures
(1) <u>Heavy Oils :</u>				
Rock (low angle)	high	high	v. good	v. good
Mud	very high	low/moderate	good*	poor
Sand	low	moderate	good	v. good
Sandy Gravel	low	moderate	poor*	moderate
Gravel/cobble	low	high	poor*	good
Marsh	very high	high	moderate*	poor*
(2) <u>Medium Oils :</u>				
Rock	high	high	v. good	v. good
Mud	high	low	good*	poor
Sand	low	high	good	v. good
Sandy Gravel	low	high	poor*	moderate
Gravel/cobble	low	low	poor*	good
Marsh	very high	high	good*	poor*
(3) <u>Light Oils :</u>				
Rock	high	low	v. good	v. good
Mud	high	low	good*	poor
Sand	low	low	good	v. good
Sandy Gravel	low	low	poor*	moderate
Gravel/cobble	low	low	poor*	good
Marsh	very high	high	good*	poor*

(See text for definition of asterisk)

In all of these cases the evaluation of the state of knowledge for the effects of spilled oil is good or moderately good but the state of cleanup technology in all four cases has been rated as poor. This group is considered to be the primary area for further research efforts. Even though the evaluation identifies that the knowledge base for the effects of spilled oil is good there is nevertheless room for improvement which could provide significant information which would assist in the evaluation of whether or not a cleanup programme should be implemented.

A second group of lower level priority shoreline types is associated with sand and sandy gravel environments. Although the ecological impact is estimated to be low on these shorelines, the potential for oil persistence is moderate or moderately high and the state of knowledge concerning the possible shoreline countermeasures that could be used on these shoreline types is poor. It is this latter point which is considered to be a useful area of research efforts. Little is known about the effectiveness or effects of mixing heavy and medium oils and sand and sandy gravel environments. If these techniques were to prove to be of value then this could alter significantly cleanup strategies for extensive lengths of low energy shorelines.

Further technology evaluations to improve countermeasure strategies could focus on mixing technology and onshore dispersion technology. These two categories of shoreline cleanup techniques are identified in Table 6.4 as having a very poor state of knowledge. The applicability of mixing techniques would be limited to sand or sandy gravel shoreline types and dispersion methods would be recommended for testing in marsh environments. Earlier in this section it was identified that mud shoreline types have a very poor state of knowledge for countermeasure techniques and the review in Section 6 indicates that the only area for a potential significant increase in technology on this shoreline type would relate to manual removal techniques.

In summary by a collation of the results described in the previous sections of this report it is evident that there are several aspects of spill technology in low energy environments that could benefit from further research. (Table 7.3).

TABLE 7.3

Areas of Potential Research Efforts that could Result in
Significant Knowledge and Technology Advances

(1) Primary

<u>shoreline type</u>	<u>oil type</u>	<u>type of research</u>
mud	heavy	countermeasures (1)
marsh	heavy	effects/countermeasures (1) (2)
marsh	medium	countermeasures (1) (2)
marsh	light	countermeasures (1) (2)

(2) Secondary

sand	heavy	countermeasures (3)
sand	medium	countermeasures (3)
sandy gravel	heavy	effects/countermeasures (3)
sandy gravel	medium	effects/countermeasures (3)

-
- (1) manual removal
 (2) physical or chemical dispersion
 (3) mixing



Section 8.0 RESEARCH RECOMMENDATIONS

8.1 Introduction

One of the primary objectives of oil-spill related research is to determine situations in which stranded oil will have an undesirable long-term and/or widespread impact if the shoreline is not cleaned. In different terms this can be expressed as defining when natural cleaning of oiled shores is or is not acceptable. This study, which focuses on low-energy shorelines in Southern Canada, recommends that our knowledge base to make these decisions is inadequate in a number of circumstances but most particularly in the three cases of:

1. heavy oils on marshes
2. heavy oils on sandy gravel beaches
3. medium oils on sandy gravel beaches

The study also suggests that further investigations on these three cases would likely yield positive results which could then be applied to the development of cleanup decisions.

A second primary objective of oil-spill related research is to evaluate the available technology for restoring contaminated shorelines in cases where such action is deemed necessary. The evaluation conducted in this study reviewed current technology and identified eight cases in which benefit could be derived by investigations on the practicality, effectiveness and effects of techniques for low-energy shorelines. The cases are:

- | | |
|--------------------------------|------------------|
| 1. mud with heavy oil | - manual removal |
| 2. marsh with heavy oil | - manual removal |
| | - dispersion |
| 3. marsh with medium oil | - manual removal |
| | - dispersion |
| 4. marsh with light oil | - manual removal |
| | - dispersion |
| 5. sand with heavy oil | - mixing |
| 6. sand with medium oil | - mixing |
| 7. sandy gravel with heavy oil | - mixing |
| 8. sandy gravel with heavy oil | - mixing |

The techniques that are involved are described only in general terms in the list. More specifically:

- (a) manual removal involves the development of an acceptable methodology and of effective techniques using hand-operated tools or equipment
- (b) dispersion includes the use of either commercial chemical dispersants or low-pressure flushing with seawater
- (c) mixing involves (i) turning over the sediments to the depth of contamination by rakes, harrows, or ploughs, or (ii) pushing the contaminated material into the lower intertidal zone to allow natural cleaning and redistribution by wave action.

The recommendations for further studies can be grouped into two separate categories:

- A. a first priority series of marsh and mud-related projects, and
- B. a second priority series of investigations on sand and sandy gravel beaches

Within each group a set of studies would address where applicable the variables and different oil types and either the effects of the oil or the practicality, effectiveness, and effects of the countermeasures.

8.2 Marsh Study on Effects and Environmental Stability

The objective of this suggested study would be to gain information on the likely long-term effects of spilled oil on marshes. In this proposed study the examination would be to compare (i) a marsh which has been previously contaminated by oil and cleaned, with (ii) a situation where the oiled marsh was not cleaned, and (iii) a non-polluted marsh system. In each case the study would look at the stability and hydrodynamic processes within the marsh to determine whether or not the marsh is erosional, stable or depositional. A primary objective would be to develop criteria that could be used for a countermeasure assessment to decide whether cleanup or natural recovery would be most appropriate in each of these three situations.

It is suggested that the following three locations be investigated:

- (1) Ile Grande, a large marsh that was polluted by the "Amoco Cadiz" spill and subsequently cleaned
- (2) Miguasha Marsh in the Baie de Chaleur which was contaminated by Bunker C from the "Golden Arrow" spill, and
- (3) a marsh which has not been polluted, but that is similar in tidal range and physical character to the first two suggested locations.

This comparative study would have the direct benefits of providing an assessment of the impact of specific oil types on marshes over a long time period. There exists sufficient documentation in Ile Grande and Miguasha marsh to provide a data base against which further studies and investigations can be compared.

8.2.1 Location

Two of the three proposed sites have already been identified in the introductory remarks. The third site could be selected at a location on the East Coast of Canada, an environment with a 2 - 3 metre tidal range. Such locations exist on the western shore of the Southern Gulf of St. Lawrence or on the Atlantic Coast of Nova Scotia or in the Bay of Fundy. It is possible that this third site, yet to be selected, could be the same as that which might be used for the marsh and mud-flats suggested experiments that are described below in section 8.3.

A possible key element in the choice of a selected site would be that the area would be one of a low population density with no unusual or highly sensitive ecological beaches. In the latter case, for example, it would be undesirable for the choice to fall on a location which was known to be a specific breeding area or larval development area for commercial or recreational marine species. Similarly an environment regularly used as a source of shellfish for human consumption should be avoided.

8.2.2 Experimental Criteria

The first step at each of the three selected locations would require a definition of the hydrodynamic and sedimentary characteristics of the marsh. The collection of data on the marsh geomorphology, the sediment type, current speeds, suspended sediment transport, sediment compaction during the tidal cycle, and definition of the sediment budget would provide the necessary physical data to describe environmental characteristics. Survey profiles in and across marsh channels and the mapping of micro-erosional features and marsh flat features could be tied in with mapping of the faunal and floral species distributions. These investigations should be carried out at both neap and spring tidal stages and during opposite seasonal conditions (i.e. Summer and Winter - growth and dormant stages).

For the two polluted marshes it would be necessary to focus attention directly on the observed and documented effects of the stranded oil and to compare contaminated and uncontaminated sections within the same marsh to determine any ecological variability. Samples of the stranded oil would be collected for geochemical analysis to determine the stage of weathering and biodegradation of the oil.

No actual spillage of oil or application of countermeasure techniques are included in this experimental design. The primary purpose is to compare the three different marsh situations and to evaluate the long term effects of the stranded oil after periods in excess of five years. It is anticipated that this type of investigation will provide valuable results that can be used to decide whether or not the spills have had a long term unacceptable impact in the two situations. The use of a third, non-polluted, marsh provides a standard against which the other two can be compared. The fact that one marsh is in North-west Europe and the other in Eastern Canada is not considered to be a detrimental aspect to the experimental design. In terms of climate, sedimentology and ecological environments the two locations are very similar despite the geographic distance between them.

8.3 Marsh - Mud-flat Suggested Experimental Design

At a single selected location a group of studies can be conducted that would focus upon the effects of heavy oil laid down upon a marsh surface and the applicability, effectiveness and effects of countermeasure techniques for heavy oil stranded on mud flats and on marshes and for light medium and heavy oils stranded on a marsh. These studies could be carried out within a single marsh system in order to provide valid comparative data sets.

8.3.1 Location

The study site should be in a meso-tidal environment, with a tidal range between 2 and 3 metres. The experimental sites themselves within the area would include (i) a relatively flat mud environment on the seaward margin of the marsh, and (ii) a sufficiently large marsh area to conduct a variety of studies on the seaward edge of the marsh and on the marsh flat. The marsh sites should be sufficiently separated from each other to avoid any problems of cross-contamination.

It is recommended that the site be selected either on the western shores of the Southern Gulf of St. Lawrence, in order to provide comparable data with the Baie de Chaleur proposed study, or on the Atlantic Coast of Nova Scotia or in the Bay of Fundy, at a location relatively accessible by road. The marshes of the North shore of the Gulf of St. Lawrence estuary, and the West Coast of Canada could undoubtedly provide suitable and adequate sites. As there exists data in the published and unpublished literature on the "Golden Robin" spill in the Baie de Chaleur and on the "Amoco Cadiz" spill in Brittany there exists a better rationale for collecting data that is closely comparable with these spill studies. The choice of a marsh environment outside of this type of climate and this type of ecosystem is not considered to be as beneficial in terms of providing an improvement in our knowledge base for the effects of spilled oil in these shoreline types.

8.3.2 Experimental Criteria

The objective of countermeasure studies based on manual cleanup of spilled oil is to develop a series of techniques, using hand tools or equipment, that can be used, following acceptable practices, in order to minimise damage to the site while efficiently collecting the stranded oil. Thus in an experiment it would be vital to compare the use of shovels, rakes, or vacuum pumps and to rate these according to the above criteria. It might be valuable also to purposefully implement the techniques in a manner designed to replicate an unrecommended procedure in order to provide comparable data to support an argument for recommended methods and techniques. This factor is considered to be very important in future countermeasure experiments. To date most experimental studies have been designed on the concept of developing the most acceptable, efficient, and lowest impact methodologies. Unfortunately this approach only provides data on the actual acceptable techniques themselves and in most cases does not provide information on how the techniques should not be applied.

The physical or chemical dispersion methods should involve the application of different methodologies in order to make evaluations similar to those described in the paragraph above.

The suggested experimental set up would be one that utilises plots of specific dimension both on the seaward edge of the marsh and on the marsh flat as well as the mud environment. These could be on the order of 10 to 20 metres in length and 5 - 10 metres in width. Oils would be distributed in a manner that would replicate the stranding of oil from the sea surface. Countermeasures would be applied after one or two tidal cycles in order to replicate the natural timing that would be involved between the stranding of the oil and the implementation of a clean up programme. Where more than one type of oil is involved, on the marsh studies, it would be necessary to replicate each of the proposed countermeasure methods and techniques for each of the three oil types.

A monitoring programme associated with these studies would involve the measurement of physical, biological and hydrocarbon characteristics before, during, and after the experiments. Some of the procedures developed as part of the BIOS shoreline studies could be applied in this context. It will be necessary to continue the data collection at intervals over a period of at least one year in order to understand the longer term of the spilled oil. It is possible to envisage a larger scale of operations in which the entire set of experiments on the marsh could be duplicated during opposite seasons, that is Winter and Summer or Spring and Autumn, to determine the effects that oil stranded at different seasons would have on the ecosystem. This latter point applies primarily to the effects studies although the impact of the countermeasures also could vary considerably during different phases of the annual cycle.

The choice of the oils to be applied in these studies should evaluate the types of oil that are carried on the sea surface by shipping in the adjacent nearshore waters. It is suggested that consideration be given to the utilisation of oil similar to that carried by the "Golden Robin", a spill of Bunker C oil on the heavy oil experiments in order to provide a data set that is reasonably comparable with the results and observations from studies conducted in the Baie de Chaleur.

8.4 Sand-Sandy Gravel Suggested Experimental Design

The purpose of this studies is to test selected countermeasures for heavy and medium oils, with a secondary objective to evaluate the effects of heavy and medium oil stranded on sandy gravel beaches. It is recommended that procedures used during the Baffin Island Oilspill studies at Cape Hatt be replicated where applicable and where possible in order to provide comparable data with that study. In this regard it is recommended in the experimental design that the Lago Medio crude oil be used for the "medium oil" studies as this will provide directly comparable data with the earlier experimental studies which were conducted on similar shoreline types.

8.4.1 Location

The selection of a low-energy sand and sandy gravel shoreline site should consider a location which is easily accessible from a populated area in order to have regular data collection and monitoring following the actual countermeasure experiments. Many such sites exist on the West Coast of Canada and these would be appropriate as this is an environment where small spills of oil are an identified risk in the region.

The tidal range should be greater than 1 metres but less than 5 metres, in order to provide results that are comparable with a wide geographical range of similar shoreline types in Southern Canada. The choice of a West Coast environment would also provide data from an ice-free area to complement that from the BIOS experiment, in terms of oil in a non-ice environment. Many sections of the East Coast of Canada are subject to ice effects in winter months similar to those experienced at the Cape Hatt BIOS study site.

8.4.2 Experimental Criteria

It is recommended that the investigations that were conducted at Cape Hatt as part of the BIOS study be used as a model for these countermeasure experiments. Some modification and improvements may be suggested to the BIOS studies but the most significant aspect would be to provide a data set that is both compatible and comparable with results already obtained from the experiments conducted on similar sediment type beaches. One modification may be to undertake studies on selected plots that deliberately utilise inappropriate techniques or methodology in order to obtain data that could support the argument for a more appropriate and correct use of the technique or methodology. An example of this for the mixing studies would be to push contaminated material above the high water mark where it would only be reworked infrequently by wave action. In this manner it would be possible to compare oiled sediments above the intertidal zone with those mixed within the intertidal zone and with oiled sediments that were pushed down into the lower intertidal zone.

In order to be compatible with the BIOS results it is recommended that a Lago Medio crude be used in the "medium oil" experiments to provide directly comparable data. The oils should be laid down in the upper intertidal zone using a method which would replicate the natural stranding of oil from the water surface. Small scale laboratory experiments may be able to determine a less involved method than that which was used at Cape Hatt with a drum-mounted ATV. A simple method that uses oil distributed from a watering can or similar receptacle may be as efficient and yet less costly and less complicated whilst achieving the same results.

It is recommended that plots in the order of 10 - 20 metres in length and 5 - 10 metres in width be used for these experiments. It would be necessary that these be separated by sufficient distance to prevent cross-contamination between plots.

8.5 Summary

This final section presents recommendations for field research projects in low-energy shoreline environments in Southern Canada that could beneficially expand our knowledge base for selected subjects which are presently poorly or inadequately understood.

- three cases are suggested for the study of stranded oil:
 - heavy oils on marshes
 - heavy oils in sandy gravel beaches
 - medium oils on sandy gravel beaches
- a series of countermeasure studies are also recommended:
 - manual removal:
 - mud with heavy oil
 - marsh with heavy, medium and light oils
 - physical and chemical dispersion:
 - marsh with heavy, medium and light oils
 - mixing:
 - sand with heavy and medium oils
 - sandy gravel with heavy and medium oils

- a study is recommended to compare two oiled marshes, one of which was not cleaned, with a non-polluted marsh; the oiled marshes have been contaminated for more than 5 years so that long-term effects could be evaluated.
- the 3 proposed studies in low-energy environments are:

(1) Marsh Stability and Long-term Impacts

Ile Grande France - polluted and cleaned
 Miguasha, P.Q. - polluted, not cleaned
 Atlantic Coastline - not polluted

- third site should be meso-tidal (2-3m range)
- no oil would be spilled in this study
- by comparison develop criteria to assess whether cleanup or natural recovery is preferable
- the study would involve physical, oceanographical, sedimentological, ecological and hydrocarbon measurements during different stages of the annual cycle
- the results could help to evaluate whether or not the spills have had an unacceptable impact on the contaminated marshes.

(2) Marsh - Mud Flat Experimental Study

- Atlantic Canada location with mud flats, marsh edge and marsh flat sites within a single system
- meso-tidal environment (range 2-3m)
- develop suggested techniques using hand tools or equipment and physical/chemical dispersion techniques that follow acceptable practices to efficiently remove stranded oil to minimise the impact of the cleanup operation

- could purposely use unrecommended procedures to provide comparable data to evaluate the recommended procedures
- could replicate certain experiments at different stages of the annual cycle (eg, spring and autumn)
- monitoring would involve physical, biological and hydrocarbon measurements

(3) Sand - Sandy Gravel Experimental Study

- West Coast location in meso-tidal environment (2-3m range) with no ice effects
- it is suggested that the design follow the Cape Hatt (BIOS) studies in many instances to provide comparable data sets; could use Lago Medio crude for the "medium oil" studies if this is considered applicable
- primary focus would be on the practical and effective use of mixing to reduce the oil contamination from unacceptable to acceptable levels
- could purposely push oil above intertidal zone to provide data on non-recommended procedures for comparison with results from recommended procedures.



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